COLONIAL NATIONAL HISTORICAL PARK

Shoreline Management Plan

for Jamestown Island, Powhatan Creek, Sandy Bay, Back River, The Thorofare, and James River Shorelines

Final Report

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Prepared for
National Park Service
Colonial National Historical Park
Yorktown, Virginia

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EXECUTIVE SUMMARY

The Shoreline Management Plan has been developed in response to the National Park Service's desire to develop a comprehensive shoreline management plan for the Colonial National Historical Park which incorporates historic sites at Yorktown and Jamestown, Virginia as well as points in between on the Peninsula between the York and James Rivers. The study area includes Jamestown Island's shoreline and those shorelines within park boundaries along the James River, Powhatan Creek, Sandy Bay, Back River, and The Thorofare. Also included is the College Creek side of the Colonial Parkway Peninsula. However, the property on the southern shore of the James River at Swanns Point is not included.

This Plan addresses the mutual desire of federal and state agencies to develop cooperative projects to improve water quality and enhance wetland habitat in the Chesapeake Bay area while preventing the loss of significant resources, particularly those archaeological sites near the water's edge. Shoreline processes and the ways they relate to hydrodynamic forcing are a main component of this study. Storm activity, in particular, over the last several years has eroded shoreline along the James River. Numerous shoreline structures, such as stone revetments and seawalls, have been installed over the years to protect uplands from erosion, but the unprotected shorelines continue to erode. This Plan will attempt to put the natural process of shoreline erosion into perspective as to potential long-term impacts to cultural and non-living resources. Also, the client's goals and objectives as well as the physical and hydrodynamic settings of the site need to be taken into consideration when determining what type of structure would be appropriate at the site. This study develops recommendations that address shoreline erosion on a reach basis for the study shoreline. The impacts of "doing nothing" to the shoreline will be assessed, and management strategies, which may include structures that are relatively non-intrusive to natural surroundings yet effective within the context of long-term shoreline erosion control, are recommended.

Six different structure types were recommended for use in the study area. These include revetments, 2 sills with different crest elevations, low broad-crested breakwaters, and 2 larger breakwaters with different crest elevations. The use of the larger breakwaters for shoreline management is appropriate when a beach is desired for shore protection, the shore protection project can be interfaced with proposed upland improvements, and when just by hardening strategic points alongshore, the process of developing equilibrium embayments begins. Sand nourishment will create a stable substrate for establishing wetland vegetation. High priority is given to eroding shorelines where infrastructure and/or archaeological resources are threatened. Eroding upland banks and shoreline headlands are addressed holistically in the context of the overall shoreline management plan.

Much of the James River's shoreline along the southwestern side of the study area already has been addressed with structures which presently provide shoreline erosion control at varying levels. The low revetment, turned sill, along the glasshouse shore protects a very low backshore from erosion, but storm waves easily overtop, break and dissipate across the low upland. The potential increase in sea level warrants further assessment and monitoring of those structures and their ability to provide long-term shore protection.

The shorelines along Powhatan Creek, Sandy Bay and Back River are fetch-limited, but tidal currents and potentially boat wakes can exacerbate shoreline erosion. Vertically-exposed eroding upland banks are considered significant in the presence of threatened infrastructure and/or cultural resources. These banks and strategic marsh headlands are the primary targets of the shoreline management plan for these reaches. Stone revetments would certainly halt the erosion of these features, but offshore sills with a sand substrate would allow the establishment of a marsh fringe which is preferred in terms of aesthetics and estuarine habitat.

Much of the upriver section of Jamestown Island's James River's shoreline has been protected by defensive measures. These include a sloped concrete seawall at the original Jamestown Fort area and a stone revetment 2,000 ft downstream. These structures are old and need to be assessed for repair/replacement. The stone revetment at New Towne is being evaluated by the Corps, and preliminary plans suggest adding armor stone and raising the crest elevation of the structure.

The remaining shoreline along Jamestown Island's southwestern shore is unprotected and eroding but becomes more stable with a widened beach toward Lower Point. Many cultural resources are located in the upland areas. The long-term plan includes breakwaters and spurs strategically-placed along the entire shore in order to begin the process of headland control. The system proposed along the beach-fronted ridge and swale system provides for low reef headland breakwater placement in front of each ridge in order to allow the equilibrium embayments to form in the swales or marsh areas. As a long-term strategy, COLO should consider placing any sand available from dredging offshore navigation channels along shore between established headlands.

The southeastern side of Jamestown Island has few cultural resources except Black Point. Black Point is the leading headland feature on the eastern end of Jamestown Island. Managing this features is important to the headland control strategies proposed along both the Thorofare and shores to the southwest. The project at Black Point is in the design phase and will include a low sill with wetland plantings and an opening at the apex of Black Point for water access a panoramic view of the James River.

Management strategies for shorelines on both sides of The Thorofare include a combination of sills, spurs, and breakwaters that are designed to protect archaeologic sites on Jamestown Island and enhance existing headland features along the Colonial Parkway shoreline. These reaches are in a low to moderate energy wave climate. There are numerous small, subtle pocket beaches whose orientations indicate the dominant direction of wave approach. The proposed strategies are aimed at enhancing existing headlands.

The water's edge along the northern shore of the James River comes relatively close to the Colonial Parkway which has several overlooks. The erosion of the fill material, used to build the Parkway originally, has provided the necessary sand for a moderate to narrow beach. Intermittent to severe bank erosion has allowed subtle geomorphic features to develop as headlands. Creeks, upland drainages, and occasional existing revetments are the headland features to address initially. The proposed strategies require ongoing monitoring to assess development of embayments between structures. A large sand fill would help alleviate that potential. Additional structures may be required alongshore to protect infrastructure.

Finally, this Plan provides a practical framework for shoreline management that offers a phased approach for erosion control with habitat enhancement. Aesthetics and function are integrated using stone, sand and wetlands plants in the design of appropriate strategies for varying wave climates, site conditions, and Park Service goals for long-term, coastal zone stewardship.

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1 INTRODUCTION

1.1 Background and Purpose

1.1.1 General Statements

The Shoreline Management Plan (Plan) has been developed in response to the National Park Service's desire to develop a comprehensive shoreline management plan for the Colonial National Historical Park (COLO). COLO incorporates historic sites at Yorktown and Jamestown, Virginia as well as points in between on the Peninsula that separates the York and James Rivers. The study area includes Jamestown Island's shoreline and those shorelines within park boundaries along the James River, Powhatan Creek, Sandy Bay, Back River, and The Thorofare. Also included is the College Creek side of the Colonial Parkway Peninsula. However, the COLO property on the southern shore of the James River at Swanns Point is not included. The total shoreline assessed for the study is about 14.6 miles (Figure 1-1).

Generally, the entire COLO shoreline on the James and York Rivers is subject to wind-driven wave-forces that cause moderate to severe shoreline erosion. Shoreline processes and the way they relate to hydrodynamic forcing are a main component of this study. Storm activity, in particular, over the last several years (*i.e.* Hurricane Gordan in 1994, Hurricanes Bertha and Fran in 1996, the 1998 Twin Northeasters, and Hurricane Bonnie in 1998) has eroded shoreline along the James River. Numerous shoreline structures, such as stone revetments and seawalls, have been installed over the years to protect uplands from erosion, but the unprotected shorelines continue to erode. This Plan will attempt to put the natural process of shoreline erosion into perspective as to potential long-term impacts to cultural and non-living resources.

This Plan addresses the mutual desire of federal and state agencies to develop cooperative projects to improve water quality and enhance wetland habitat in the Chesapeake Bay area while preventing the loss of significant resources, particularly those archaeological sites near the water's edge. Any shoreline management plan must include the goals of the client. Specific goals of COLO, described in a following section, will be incorporated into the analyses in order to produce a comprehensive shoreline management plan. This study also develops recommendations that address shoreline erosion on a reach basis. The impacts of "doing nothing" to the shoreline will be assessed. Recommendations also may include shoreline protection strategies that are relatively non-intrusive to natural surroundings yet effective within the context of long-term shoreline erosion control. This can be accomplished with a combination of stone structures such as sills, revetments, and/or breakwaters along with sand nourishment to create a stable substrate for establishing wetland vegetation. High priority is given to eroding shorelines where infrastructure and/or archaeological resources are threatened. Eroding upland banks and shoreline headlands are addressed holistically in the context of the overall shoreline management plan.

1.1.2 Site Description

COLO, in the southern Tidewater region of Virginia, has many cultural resources since it encompasses most of Jamestown Island, which was the site of the first permanent English settlement in North America, and Yorktown, the site of the culminating battle of the American Revolution. The park occupies a portion of the peninsula between the James and York Rivers. The Shoreline Management Plan includes only the shoreline of Jamestown Island and those shorelines within park boundaries along the James River, Powhatan Creek, Sandy Bay, Back River, and The Thorofare. Also included is the College Creek side of the Colonial Parkway Peninsula. Neither the COLO property on the southern shore of the James River at Swanns Point nor its York River shore is included in this report. The total shoreline assessed for the study is about 14.6 miles (Figure 1-1).

Jamestown was America's first permanent English settlement in North America. However, the area had been used for hundreds of years before the colonists' arrival in 1607 by the Powhatan Indians. The original site of Jamestown served as Virginia's capital until 1699 but had become farmland by the mid-1700s. The site presently is administered jointly by the National Park Service and the Association for the Preservation of Virginia Antiquities (APVA). APVA acquired their property on Jamestown Island, which consists of the archaeological remains of the original fort and the 1640s church tower, in 1893. The National Park Service acquired the rest of the Island surrounding the APVA property in the 1940s.

In preparation for the 1957 commemorative Jamestown festival, the 23-mile Colonial Parkway, which was begun in 1930 and connects Yorktown and Jamestown, was completed; it provides an aesthetic drive through natural environments with few modern intrusions. Generally, anthropogenic impacts have been limited to several large events. Perhaps the most significant change along the shoreline was the construction of the Jamestown Isthmus and channel bridge which connected the island to the mainland via the Colonial Parkway. At the same time, the mouth of College Creek was partially filled to create the Colonial Parkway crossing.

1.1.3 COLO's Land Use Goals

Resource Management Goals are outlined in COLO's General Management Plan and Resource Management Plan. Selected goals that pertain to this study are listed in the following subsections.

1.1.3.1 General Management

For the entire park, the goals and objectives are:

- to protect, enhance, interpret natural resources in a manner consistent with applicable policies and regulations while supporting cultural resource objectives.
- to cooperate with organizations, individuals, and other agencies to further park objectives and encourage compatible land uses.

For Jamestown, in particular, they are:

- in areas without evidence of habitation, to maintain the natural environment in ways that suggest the conditions of the 1607 forest environments.
- to promote a sense of the primitive isolation Europeans experienced in 1607.

For other natural resources, they are:

- to develop an up-to-date inventory and data base of natural resources.
- to develop an active resource monitoring program.
- to cooperate with public agencies and with owners of properties that adjoin the park to promote resource preservation and monitoring of land uses that could affect park management.

1.1.3.2 Resource Management Plan

The goals and objectives toward increased general resource management include:

- to preserve, protect, and interpret cultural resources, museum collections, and natural processes/resources in their environment.
- to achieve better understanding of cultural and natural processes through research and monitoring to guide management activities and interpretation including ecologically sound decision making; to gather and evaluate information through research and monitoring in natural science, visitor use, archaeology, history, and land uses to guide decision making and management actions.
- to develop and maintain cooperative protection strategies with federal, state, and local government agencies, community groups, corporations, and individuals to protect the integrity of the natural and cultural environments within and surrounding the park.

For water resource management they are:

- To develop an up-to-date water resources inventory and data base compatible with the park's GIS and database management systems.
- To manage floodplain and wetland resources in a manner that will protect their beneficial attributes and uses.

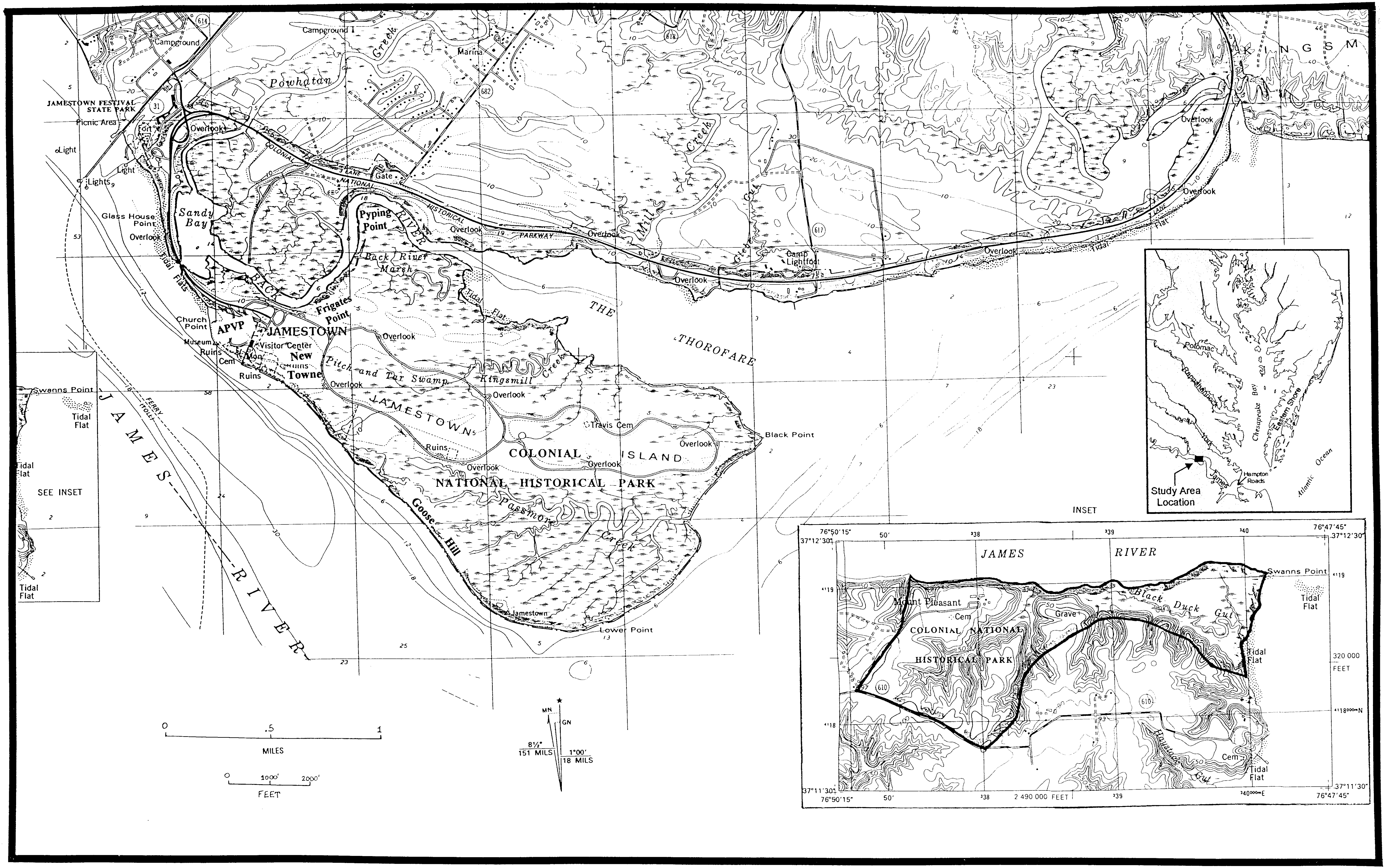


Figure 1-1. Study area location map.

1.2 Components of the Shoreline Management Plan

1.2.1 Existing Shoreline Conditions

Oblique, low-level aerial video of COLO's shoreline was obtained in the fall of 1997. This imagery was compared to oblique aerial video taken in 1993 as well as oblique slides from 1974 in order to evaluate changes in the shore zone. This semi-quantitative assessment has the benefit of showing detailed morphologic shoreline changes. The shoreline reach designations used in this document are the same as those contained in Byrne and Anderson (1978) and Hardaway *et al*. (1992). However, several new reaches were designated where previously none existed.

Shoreline type and land use were categorized and coded onto mylar copies of 7.5 minute USGS topographic maps, digitized, and then input to the Arc/View program for ease of comparison and display. The error maybe +/-100 ft over a mile of shoreline. Shoreline conditions include, in part, whether it is marsh or upland bank, eroding or stable, hardened with structures or otherwise altered (Table 1-1). Beaches are not specifically designated in the shoreline condition but tend to occur in front of eroding upland banks. The miscellaneous shoreline condition category refers to sections of shore that are not natural but have had unsuccessful shore protection projects placed along their shore. It can include designed structures that have failed or performed poorly as well as debris, such as broken concrete, that has been dumped in an attempt to abate erosion. Land use categories were fitted to Jamestown Island and COLO nomenclature and include unmanaged wooded, historical, and recreational.

The proximity of marine resources to shore reaches also was assessed. There were no oysters or submerged aquatic vegetation (SAV) and no significant tidal flats. These features will be discussed no further.

1.2.2 Shoreline Change, Geology and Geomorphology

Understanding long-term shoreline change is critical in assessing shoreline reaches. The method used for this assessment involves digitizing historic shorelines into a database. Four shorelines were plotted for the Plan utilizing data in Virginia Institute of Marine Science's (VIMS) Geographic Information System (GIS) database; these shorelines are dated 1874, 1942/52, 1979/83 and 1990. The shore information came from topographic maps produced by the U.S. Geological Survey; specific information on the data is in the Federal Geographic Data Committee-compliant metadata archived by COLO. Shoreline change maps were produced, and the rates of change were determined and referenced to a baseline.

Other "layers" of GIS information contained in the COLO archives were added to the database. The data layers include cultural resources (archaeological) and infrastructure. These features were assessed in terms of coincidence with areas of shoreline erosion and flooding to determine priority of action and what shoreline strategy should be employed.

Shoreline morphology and erosion patterns were evaluated in order to determine the long-term shore response to the hydrodynamic processes. Aerial photos from 1937 and 1963 were used to supplement the shoreline change analysis. The geologic underpinnings relative to shore morphology were assessed using previous reports and field observations. The geology of an area can cause shorelines to erode unevenly. Adjacent shore types, such as uplands and marsh and even unprotected shore segments that border protected shores, result in the development of different morphologic expressions along the shore. The net effect is that beaches and shorelines tend to orient themselves into or parallel with the dominant direction of wave approach. The morphologic expressions were compared with the wave climate analysis to see if a correlation exists. Generally, beach and shoreline planforms will reflect the net impact of the impinging wave climate. When the wave climate analysis model agrees with the morphologic expression, then the impacts of proposed shoreline management strategies can be assessed more accurately.

Table 1-1. Shoreline attribute code list (*after* Hardaway *et al*., 1992).

Condition Code		Land Use Code		
Code	**Structure**	**Code**	**Land use**	**Explanation**
0	Boundary	23	No aerial coverage	creeks
1	**Hardened - Riprap**	30	Private - residential	single or multi-family
2	**Hardened - Bulkhead**	31	Private - agricultural	crops, pasture, tree farm
3	Jetty	**32**	**Private - unmanaged, wooded**	**woodland**
4	Groins	**33**	**Private - unmanaged, nonwooded**	**marsh, beaches, open areas**
7	Breakwaters	34	Recreational - County/City	parks, public beaches
9	Groinfield and Bulkhead	**35**	**Recreational - State/Federal**	**parks, military rec centers**
10	Groinfield and Riprap	**36**	**Recreational - Private**	**campgrounds, local shore access**
11	Groinfield, Bulkhead &Riprap	37	Federal - Residential	barracks, jails, public housing
13	Bulkhead and Riprap	**38**	**Federal - unmanaged, wooded**	**woodland**
18	Upland - Unstable, No structures	**39**	**Federal - unmanaged, nonwooded**	**marshes, beaches, open areas**
20	**Miscellaneous**	40	Commercial	marinas, fish docks, etc.
21	Closure line	41	Industrial	shipyards, power plants
22	**Upland - Stable, No structures**	42	State - residential	barracks, jails, public housing
23	No aerial coverage; creeks	43	State - agricultural	parts of State Parks
24	**Marsh - Unstable**	44	State - unmanaged wooded	woodland
25	**Marsh - Stable**	45	State -unmanaged nonwooded	marshes, beaches, open areas
		46	County/City - residential	jails, public housing
		47	County/City - agricultural	crops, pasture, tree farm
		48	County/City - unmanaged wooded	woodland
		49	County/City - unmanaged nonwooded	marshes, beaches, open areas
		50	**Miscellaneous**	**Obvious military activity, public roads and access, bridges, public buildings, utility easements**

1.2.3 Wave Climatology and Sea-Level Rise

In order to quantify the general wave climate acting upon the James River shoreline, it was necessary to evaluate the local wind climate since waves impacting the shore in the study area are wind-driven. A long-term wind data set exists at Norfolk International Airport (ORF) (Table 1-2). A general wind field evaluation was used to model wave conditions on the James River. Procedures developed by Sverdrup and Munk (1947) and Bretschneider (1966) and modified by Kiley (1980) were used for this analysis.

Offshore wind and wave directions are assumed the same to a point. However, when crossing the -15 ft MLW isobath, the waves enter the nearshore shoaling region and must be evaluated using a hydrodynamic wave refraction model. We used RCPWAVE (Ebersole *et al*., 1986) for that purpose. The results of the RCPWAVE analysis are wave vector plots showing wave attenuation and refraction across the nearshore and shoreline that allow us to determine the net movement of littoral materials.

Increased water levels pose a threat to certain resources regardless of the wave conditions impacting the shoreline. For this reason, another component of the wave climate assessment was the determination of the frequency of storm surges and flooding across Jamestown Island. This assessment is based, in part, on long-term tidal data from the National Oceanic and Atmospheric Administration (NOAA), U.S. Army Corps of Engineers (Corps), and Boon *et al*. (1978). Analyses such as these are critical when determining the potential impact of the local wave climate and storm surge on the shoreline. Consideration of these impacts is an important element in the design of a shoreline management strategy particularly the dimensions of structural options.

When developing a management plan to protect cultural resources that would seem to have an "infinite" life span, sea-level rise is an important consideration. The position of sea level has profoundly impacted the development of Jamestown Island. In particular, sea-level change during the Pleistocene Epoch and sea-level rise since the end of the last glacial maximum is described in order to show how the position of sea level has influenced the geology and geomorphology of Jamestown Island. The objective of the Plan is to provide a meaningful assessment of the impacts of sea-level rise over the long-term so as to develop recommendations for the continued protection of cultural resources as sea level rises in the future.

Table 1-2. Summary wind conditions at Norfolk International Airport from 1960-1990.

		WIND DIRECTION								
Wind Speed (mph)	**Mid Range (mph)**	**South**	**South west**	**West**	**North west**	**North**	**North east**	**East**	**South east**	**Total**
< 5	3	5497* 2.12⁺	3316 1.28	2156 0.83	1221 0.47	35748 13.78	2050 0.79	3611 1.39	2995 1.15	56594 21.81
5-11	8	21083 8.13	15229 5.87	9260 3.57	6432 2.48	11019 4.25	13139 5.06	9957 3.84	9195 3.54	95314 36.74
11-21	16	14790 5.70	17834 6.87	10966 4.23	8404 3.24	21816 8.41	16736 6.45	5720 2.20	4306 1.66	100572 38.77
21-31	26	594 0.23	994 0.38	896 0.35	751 0.29	1941 0.75	1103 0.43	148 0.06	60 0.02	6487 2.5
31-41	36	25 0.01	73 0.03	46 0.02	25 0.01	162 0.06	101 0.04	10 0.00	8 0.00	450 0.17
41-51	46	0 0.00	0 0.00	0 0.00	1 0.00	4 0.00	4 0.00	1 0.00	0 0.00	10 0.00
Total		41989 16.19	37446 14.43	23324 8.99	16834 6.49	70690 27.25	33133 12.77	19447 7.50	16564 6.38	259427 100.00

*Number of occurrences ⁺Percent

1.2.4 Field Verification

In order to verify GIS and shore change analysis, two field trips were done by boat. Field checks of shore type, bottom stability, and bathymetry are incorporated into this effort which included personnel from COLO, the Corps and VIMS.

1.2.5 Shoreline Monitoring Sites

Black Point and Glasshouse Point were identified early in this study by COLO personnel as sites containing cultural resources that were threatened by erosion or flooding. A baseline was established, and a shoreline survey was performed at both Glasshouse Point and Black Point in order to determine the dimensions of the shore zone as they relate to the management strategy analysis. The shore survey data are shown in Appendix 1. The vertical datum for both sites is mean low water (MLW).

VIMS established two monitoring sites along the York River shoreline as part of the *Chesapeake Bay Shoreline Study* (Hardaway *et al.*, 1991), a joint project among the Corps, VIMS, and Department of Conservation and Recreation (DCR). These sites were monitored between 1987 and 1990 and were re-occupied for this study. Surveys were performed during the fall of 1997 and spring of 1998.

One of the existing monitoring sites is located along the Colonial Parkway just upriver of the Yorktown Naval Weapons Station. This project was designed by VIMS/DCR personnel, built in 1985 by personnel from COLO and the U.S. Army's Fort Eustis, and represents the practical use of offshore breakwaters for erosion control. The other site, known as the Yorktown Bays, consists of three pocket beaches just downriver of the COLO picnic area near Cornwallis' Cave. These pocket beaches are "classic" spiral-shaped bays created by large headlands and represent an important element in shoreline management -- headland control. The purpose of re-occupying these sites is to gain further data on the long-term performance of these shoreline strategies which protect the shoreline, allow a stable beach and intertidal zone to exist, and will not be a solid barrier between the upland and the river.

1.2.6 Reach Assessment and Recommendations

When the previous analyses were completed, shore reach assessment was performed. This assessment incorporates COLO's land use goals, shoreline conditions and their potential for change. The purpose of assessment is to determine the "immediate" need for any specific shoreline management strategy and how the strategies fit into the long-term plan.

A shoreline management strategy is recommended for each shore reach. The strategies may include any of the following:

1. Do nothing;
2. Defensive approach (stone revetments and/or sills with wetlands plantings);
3. Offensive approach (stone breakwaters and beach fill with wetlands planting);
4. Headland control (stonebreakwaters strategically placed).

One or a combination of the above strategies may be appropriate for a given reach depending on the availability of funds and project goals. Phasing shoreline management strategies through time also is addressed since it is usually the more prudent and cost-effective approach. All strategies integrate upland management as part of the plan, but bank grading may be recommended in only a few instances. The natural vistas will be maintained if the banks are not graded but instead are allowed to erode.

2 GEOLOGIC HISTORY of JAMESTOWN ISLAND

In order to develop a plan for effective management of the Colonial National Historical Park's James River shoreline, it is necessary to have an understanding of the region's geology. This section will describe the geology and geomorphology of Jamestown Island and adjacent areas as reported in the literature, primarily from Johnson and Hobbs (1994). The intent is to present a physical and geographic framework which can be used in the projection of possible future modifications of the Park's shore. Detailed stratigraphic information is presented in Appendix 2.

2.1 Geomorphic Setting

Jamestown Island is bounded on the north by Back River and The Thorofare, and on the west, south and east sides by the James River. According to Johnson and Hobbs (1994), the island is a low, sub-rectangular landmass about 3 miles long and approximately 1.5 miles wide (Figure 2-1). The island is surrounded by a subaqueous platform ranging in width from about 0.5 mile to less than 0.2 mile. The island is divisible into four geomorphic regions: the Back River marsh, the central upland, the Passmore Creek lowland, and the Lower Point platform. Each area is characterized by distinctive, different-aged landforms such as broad marshes, linear ridges and swales, and recurved spits. The various regions also are underlain by sediments of different lithology and ages, most of which are aggradational in nature and were created during periods of higher sea level in the past. The morphology of each is described briefly in the following sections from Johnson and Hobbs (1994).

2.1.1 Back River Marsh

This marsh trends east-west along the northern edge of Jamestown Island. Back River meanders through the marsh which varies in width from 0.3 to 0.6 mile and is about 1.5 miles long. The marsh occupies the flooded and filled paleovalley of the late Pleistocene Powhatan Creek and underlain by a thick sequence of Holocene fetid muds and sands estimated to be more than 50 ft thick (Johnson and Hobbs, 1994). Sandy Bay, which lies at the western end of Back River marsh, is a shallow body of open water created when the isthmus connecting Jamestown Island to the mainland was breached early in the 18th Century. The marsh surface is cut by numerous shallow channels and is intertidal. The dominant plant is Spartina.

2.1.2 Central Uplands

The central uplands are the area of Jamestown Island most visited by tourists and the site of most cultural and agricultural activity by the early settlers. These land uses reflect the higher elevations which have better-drained soils and provide protection from storms. The uplands are divisible into a northern complex, Church Point ridge and swale, a central Pitch and Tar swale, and a southern high ground, the Confederate Ruins ridge. The Church Point ridge and swale is comprised of a series of low, slightly curved, ridges orientated northwest to southeast, mostly less than 12 ft above mean sea level. The ridges range in length from about 800 ft to more than 4,200 ft and are up to 500 ft in width. The northwestern termini of ridges along Back River are eroding. The ridges and swales are underlain by a basal sand sequence mantled by a thick clay-silt cap 5 to 8 ft thick (Johnson and Hobbs, 1994).

Pitch and Tar swale is comprised of the lowland occupied by Pitch and Tar Swamp as well as Kingsmill Creek and its tributaries. Most of the trough is covered by marsh which divides the island into two parts and extends westward onto the APVA land. The wetlands probably impeded travel between the northern and southern parts of the island in the early days of English colonization. Main access was around the western end of the island near the ruins of the Jamestown town site. The area occupied by this lowland has increased during the last 400 years as sea level has risen.

Confederate Ruins ridge lies between Pitch and Tar trough and a low scarp north of Passmore Creek. The main ridge trends in an east-west direction. The western end of the ridge is a broad platform about 1,050 ft wide, but to the east, short, arcuate ridges extend northeastward from the main ridge. The arcuate ridges are sand spits prograded eastward during the late Pleistocene. The ridges are covered by a clay-silt cap (Johnson and Hobbs, 1994).

2.1.3 Passmore Creek Lowland

The landscape of the southern part of the island, the Passmore Creek lowland, is dominated by a series of generally east to northeast-trending, straight to slightly curved ridges with intervening swales, and Goose Hill Ridge on the southwestern margin of the lowland. The swales are covered by brackish water marshes. Eight meandering tidal streams, which occupy the swales, flow northeastward into Passmore Creek. The morphology of the ridges vary from continuous to discontinuous, gently sloping to undulatory and are asymmetrical (usual state) to symmetrical in cross section. The ridges rise more than 5 ft above the marsh and generally decrease in height and length toward Lower Point. The ridges are underlain by late Pleistocene regressive beach or point bar deposits, and the marshes rest on Holocene fluvial-estuarine and paludal sediments (Johnson and Hobbs, 1994).

Goose Hill ridge extends from Jamestown town site southeast to Lower Point. The ridge, comprised of beach and dune deposits, is an undulatory landform. The higher elevations (5 to 15 ft MLW) are dune-covered Pleistocene ridges, and the lower elevations are covered by beach and dune sands that have been swept over the swales and marsh deposits during the late Holocene. During major tropical storms and northeasters, most of the Passmore Creek lowland is inundated.

2.1.4 Lower Point Platform

This platform is a shallow-water shelf that surrounds Jamestown Island on the west, southwest, southeast and east sides of the island. The water depth over the platform is less than 12 ft but averages about 4 ft deep. The shoreline of the island marks the upper grading of the platform, and the thalweg of the James constitutes its deeper margin. The platform is covered by a thin veneer of very recent sediments over older Holocene fill or beveled Pleistocene sediments. The platform appears to be a planation surface cut mostly during the last 500 years (Johnson and Hobbs, 1994). The principal agent for this erosion is storm-generated waves and current possibly augmented by boat wake and ship-propeller turbulence. At the west end of Jamestown Island, the platform is over 1,500 ft wide. It narrows to less than 400 ft at old Jamestown, and on the eastern end of the island, it increases to more than 2,000 ft wide.

The James River thalweg is a discontinuous trough of deep water that lies 1,500 ft off the southwestern shore of Jamestown Island. The trough varies in depth from less than 25 ft to more than 55 ft and in width from about 2,000 ft to a shallow trough more than a mile wide. The thalweg represents the unfilled remnant of the Wisconsinan glacial paleovalley of the James River.

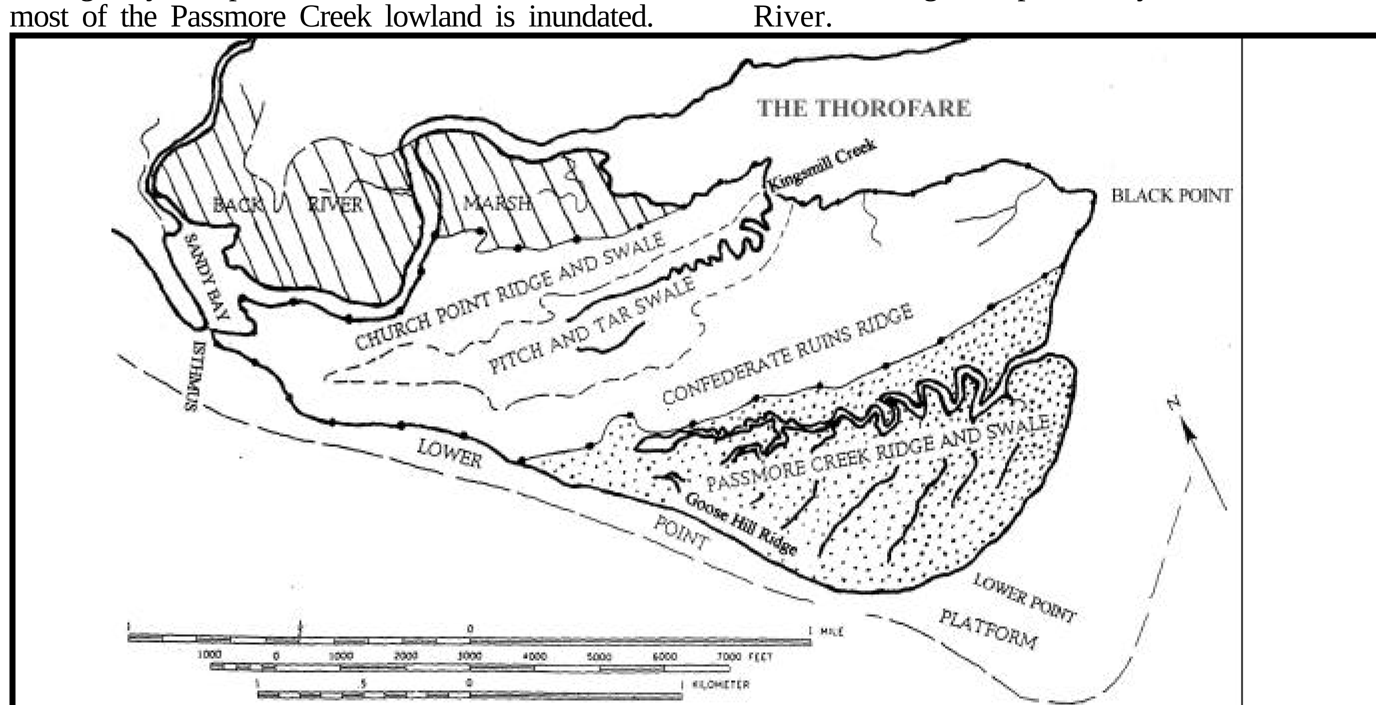


Figure 2-1. Map of Jamestown Island showing geomorphic features (*after* Johnson and Hobbs, 1994).

2.2 Geologic Setting and Sea-Level Change

The geologic history of Jamestown presented here is interpreted from existing borings, aerial photographs, and topographic and planimetric maps and has been elucidated in a preliminary report on the development of the island described in Johnson and Hobbs (1994).

During the Tertiary Period (Table 2-1), the Coastal Plain was covered by shallow seas or emergent for long periods of time producing thick sequences of marine and estuarine formations separated by bounding unconformities. These preserved Tertiary and Quaternary (Figure 2-2) formations were deposited under different circumstances. The Tertiary were formed during a shallow, continental shelf state while the Quaternary formations were deposited in rivers, estuaries, bays, barrier islands and nearshore marine conditions that are comparable to the present lower Chesapeake region.

Jamestown Island was built upon the Eastover Formation which was deposited as muddy sand in a shallow sea that spread westward beyond what is now Richmond about 7 million years ago. When sea level subsequently fell, the Coastal Plain became emergent again. Between the time of emergence after the deposition of the Eastover in the Miocene and the Shirley Formation in the middle Pleistocene, the outer Coastal Plain was repeatedly flooded and exposed. The growth and wastage of large continental glaciers during the late Pliocene and Pleistocene controlled these oscillations of sea level. The courses of major Coastal Plain rivers, such as the James and its larger tributaries, were established in the late Pliocene or early Pleistocene.

As the Illonian glaciers melted (glacial maximum approximately 150 thousand years before present (Ka)), the Chesapeake lowland was again inundated. During this highstand, sea level rose and fell short distances. During these intervals (Table 2-1), the Sedgefield, Lynnhaven and Poquoson members of the Tabb Formation were deposited (Figure 2-2). At the time of deposition of the Lynnhaven, relative sea level was about 18 ft above present, and the landscape of Jamestown Island area was quite different. A major headland lay to the west, Powhatan Creek flowed southward directly into the James, and the site of Jamestown Island was shallow-water, estuarine bottom. Sand eroded from the headland and was carried eastward, building a spit across the mouth of Powhatan Creek. With time, the eastward growth of the spit deflected Powhatan Creek to an easterly course. The prograding spit eventually grew as far east and northeast as the mouth of Kingsmill Creek. This spit permanently diverted the course of Powhatan Creek through Back River and The Thorofare.

A minor withdrawal of the sea left the proto-Jamestown Island emergent. The subsequent rise of sea level to about 10 ft above present level resulted in erosion along the southern edge of the island and the formation of the low scarp north of Passmore Creek. Erosion of the western headland began again. This time a series of curved ridges either point bar or regressive beaches were constructed successively to the west and south of the island, the oldest being in the north.

Following the formation of the Passmore Creek ridges and swales, sea level fell to more than 300 ft below present during the Wisconsinan glaciation (glacial maximum approximately 18 Ka). In response to the lower base level, the James eroded a deep valley more than 100 ft below present sea level along the southern margin of the island. Streams on Jamestown Island, such as Powhatan and Passmore, responded by deepening their valleys. About 18,000 years ago, late Wisconsinan continental glaciers began to melt, and sea level began to rise. The rise of sea level reduced the gradient of streams, such as the James River and Powhatan Creek, and caused them to fill their valleys with coarse sand and gravelly sediments. This event was time transgressive, probably beginning in the lower James' thalweg about 15 to 16 Ka years ago and moving upstream to Powhatan Creek about 5 to 7 Ka years ago. With the continued rise of sea level, the deeper valleys were flooded by tidal waters and finger marshes and fringing swamps developed.

The first human inhabitants apparently entered the Jamestown area when the James River was still a unidirectional freshwater stream and was entrenched more than 200 ft below the uplands to the north and south. Although sea level had risen to about 100 ft below present by 10 Ka, the rivers of the lower Chesapeake region remained freshwater (Figure 2-3-1). As the climate continued to warm and sea level rose, a tongue of the ocean extended into Hampton Roads and the lower Chesapeake but did not reach Jamestown. As sea-level rise slowed by 5 Ka, the entire lower Bay had flooded, creating the modern Chesapeake and its tributary estuaries (Figure 2-3-2). This rise resulted in the filling of the James River paleovalley and its tributaries. The rate of sea-level rise slowed significantly after 5 Ka. By 2.5 Ka, the modern Chesapeake Bay had formed, but sea level was 8 to 10 ft lower than present. The James River was narrower, and the marshes did not extend as far inland (Figure 2-3-3). Shellfish and other aquatic resources were probably similar to those of today.

Sea level in the Chesapeake Bay change was slow during most of the last millennium, rising less than 1.5 ft or approximately 2.2 inches per 100 years (Kearney, 1996). In the last 500 to 1,000 years, the James River spilled out of its thalweg and began the process of cutting the Lower Point platform (Figure 2-3-4). Recession of the bluff on the west and east ends of the island was faster than along the Goose Hill area because of the greater exposure to waves and currents created by tropical storms and northeasters. The isthmus connecting the mainland and Jamestown Island was breached early in the18th Century, changing the flow of Powhatan Creek and life on Jamestown Island. The slow rise in sea level continued until about 1850 when data indicate a sharp inflection point on the sea level curve (Kearney, 1996).

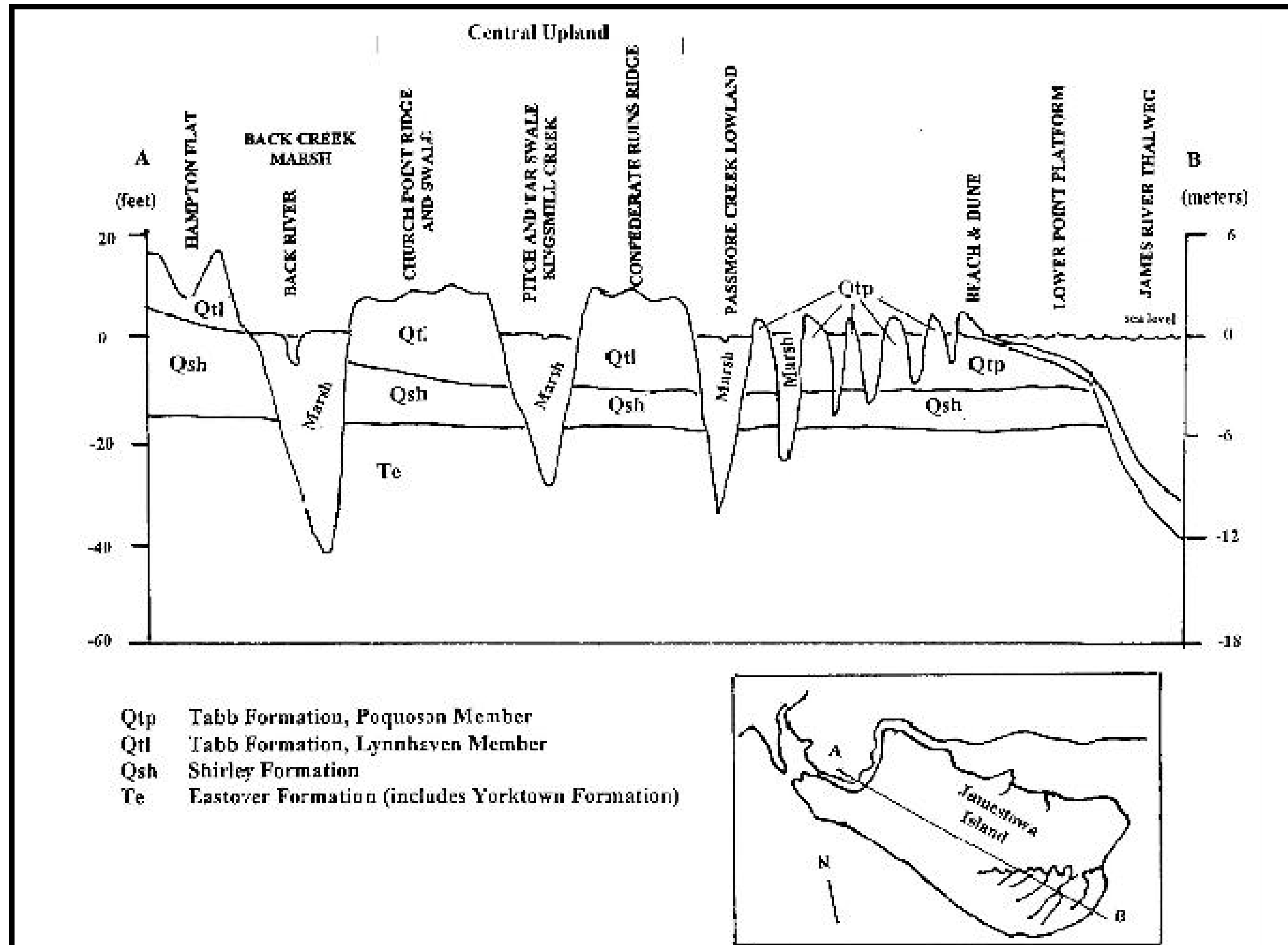


Figure 2-2. Stratigraphic cross-section of Jamestown Island (*after* Johnson and Hobbs, 1994).

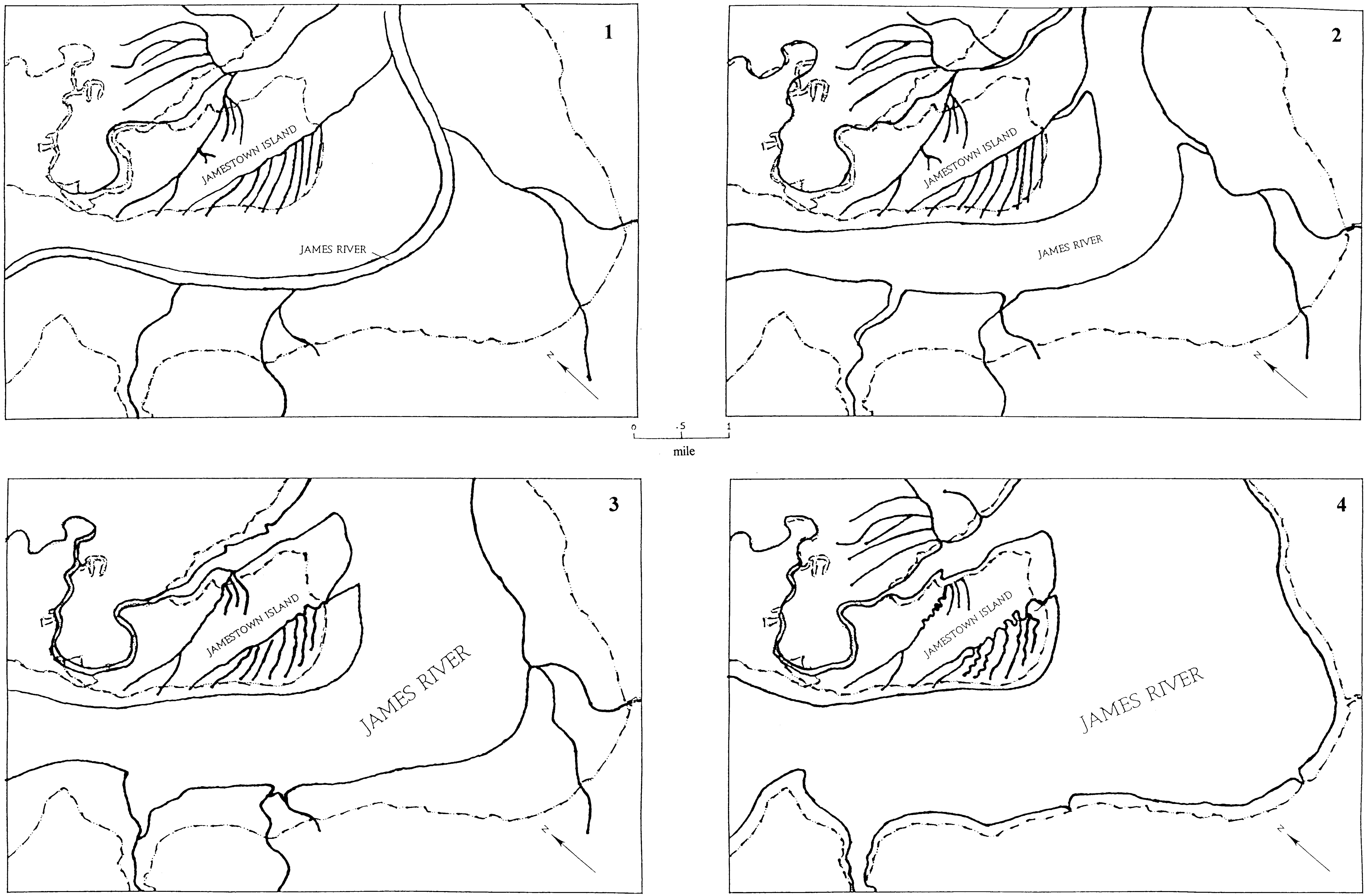


Figure 2-3. Map showing paleogeography of Jamestown Island approximately 1) 10,000, 2) 5,000, 3) 2,500, and 4) 400 years before present. Solid line is the paleoshore while the dash-dot is the present shoreline (*after* Johnson and Hobbs, 1994).

Table 2-1. Geologic time scale terminology used in this report with formations and glacial episodes noted.

Period	Epoch	Formation	Member	Years BP*
Quaternary	Holocene			11,000 ← Wisconsinan Glaciation
	Pleistocene	Tabb	Poquoson	80,000
			Lynnhaven	100,000
			Sedgefield	120,000 ← Illinoian Glaciation
		Shirley		184,000
		Chuckatuck		
		Charles City		
		Windsor		1.8 Mill
Tertiary	Pliocene	"Moorings" unit Bacons Castle Chowan River Yorktown		5 Mill
	Miocene	Eastover		23 Mill
	Oligocene			38 Mill
	Eocene			54 Mill
	Paleocene			65 Mill

*Years next to lines represent boundaries in the geologic time scale. Years between lines represent the approximate year of either sea-level highstand (formations) or lowstand (glaciation).

Sea level continues to rise today at a much higher rate than the last 1,000 years. Data from a Hampton Roads tide gage showed that between 1927 and 1980, the yearly means of sea level increased about 1.6 inches per decade or 16 inches per 100 years (ASCE, 1998). The beach and dune tract along Goose Hill continues to migrate northeastward under storm-generated waves and tides and in response to the rise of sea level. As a consequence, the Lower Point platform in this area is slowly widening. The Pleistocene ridges are being eroded and eventually the Passmore Creek lowland will be inundated. Seawalls and riprap were installed during this century to protect the western end of the island and segments of the other shorelines.

2.3 Shoreline Erosion

Erosion rates along estuarine shorelines are a function of two unrelated factors -- wave climate and the site-specific character of the sediments. The different amount of energy required to resuspend, hence erode, individual types of sediment determines the variations in erosion rates between sections of shore exposed to equal amounts of impinging energy. More energy, in terms of waves and currents, is required to resuspend silts, clays, coarse sands, and larger-sized sediments than medium- and fine-grained sands. Thus, given equal exposure to waves and currents, the "energy" of the James River, shores consisting of medium- and fine-grained sands will erode more rapidly than deposits of clays or silts, which exist in lagoonal, estuarine or marsh deposits.

Along the Jamestown Island shore on The Thorofare, the low upland banks (ridges) tend to erode faster than adjacent marsh (swale) shorelines. This is often why marshes become headland features as shoreline erosion proceeds through time (Hardaway, 1980). Sediments from eroding upland banks supply the beach zones found in front. Beaches and upland banks tend to orient themselves into the direction of dominant wave approach, especially if there is a "hard" point, an erosion resistant feature, upon which sand will accumulate on one side and the bank will cut on the other in the alongshore direction. This effect is illustrated in the next section on the monitoring sites along the York River. Marsh shorelines erode irregularly and "reading" the morphology is more difficult especially when sand is lacking in the shore zone. However, small pocket beaches within the marsh system will indicate the direction of most recent wind/wave action.

Jamestown Island is similar to several other island or point/bar features around Virginia's Chesapeake Bay estuarine system. These include: the Goodwin, Catlett, and Allen Islands in the York River; Mulberry Island and Ragged Point in the James River; and Belle Island and Parrot Island on the Rappahannock River. All are ancient relic point bars and are products of previous stands of sea level.

2.4 Monitoring Shore Geomorphology

As discussed previously, shoreline geomorphology refers to the shape a shoreline evolves from and to over time. The more exposed the shoreline is to an open fetch and the wind generated wave field, the greater the impinging wave energy. When headlands, either natural or constructed, are located along a shore, the beach planform responds to impinging energy in the manner shown in Figure 2-4 as discussed in Sylvester (1972) and Sylvester and Hsu (1989). This method, known as the Static Equilibrium Bay (SEB) model, uses the net or dominant direction of wave approach to determine the beach or shoreline shape. Beaches and offsets of the upland bank can indicate the net movement of littoral sands since sediment transport is related to the impinging wave climate.

The Shoreline Studies Program at VIMS has many shoreline monitoring sites around Chesapeake Bay. Two of these sites are located on COLO property (Figure 2-5). In order to assess long-term shore morphology of similar sites for this project, we evaluated two shoreline projects that were monitored between 1986 and 1990 (Hardaway *et al.,* 1991). Both occur along the southern side of the York River. The Yorktown Bays site is an example of a naturally-formed series of pocket beaches with artificially-hardened

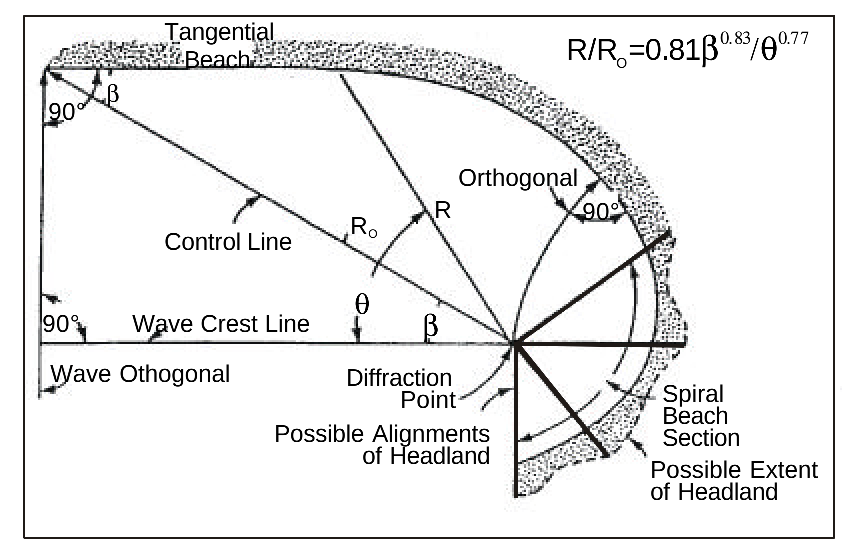


Figure 2-4. Parmeters of a static equilibrium bay (*after* Hsu et al., 1989)

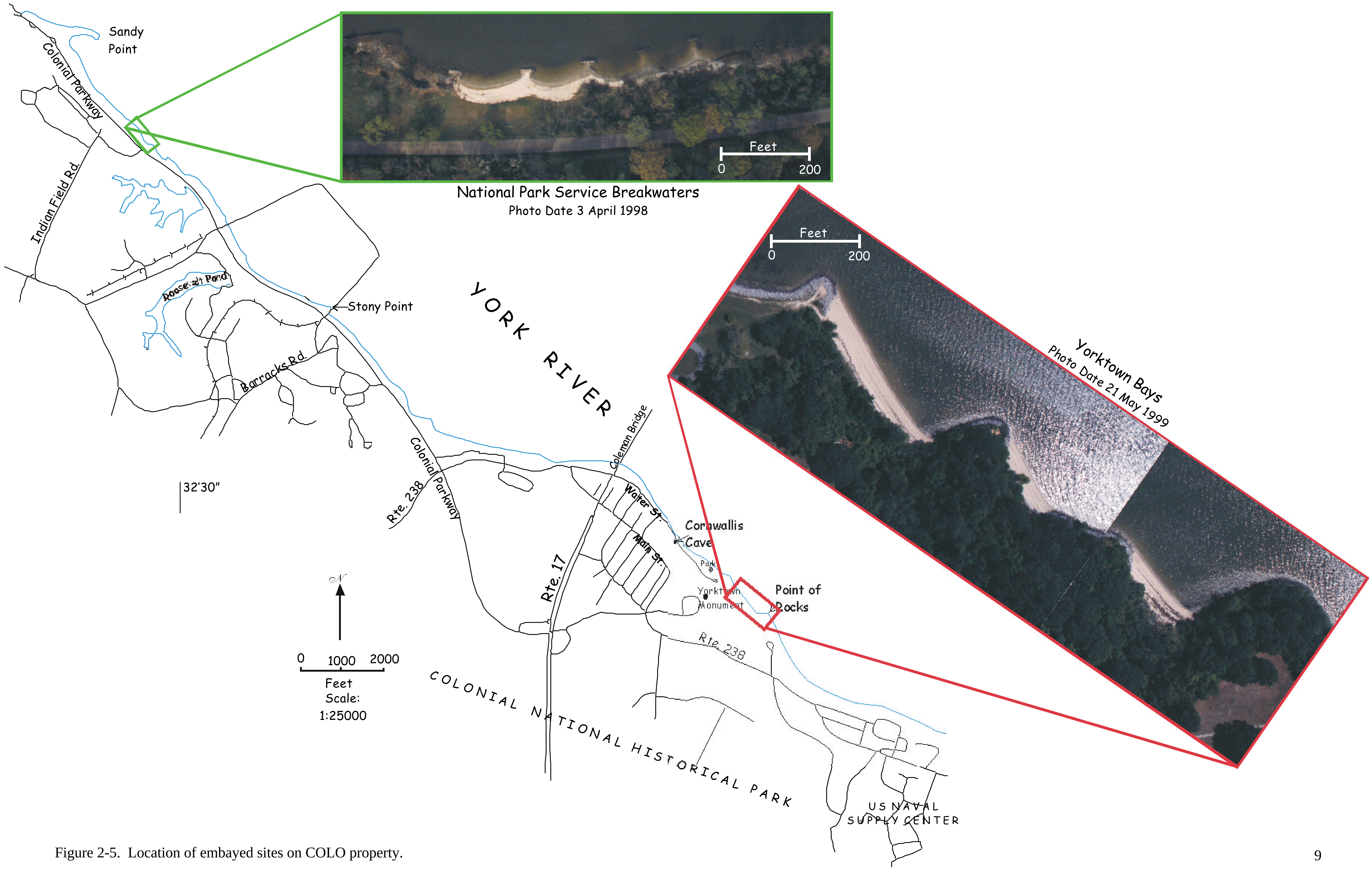


Figure 2-5. Location of embayed sites on COLO property.

headlands. These three embayed beaches have attained a high degree of stability over the past 50 years. These sites were re-occupied and surveyed. Comparison with early surveys was done to assess 8 years of wave action on the beach planform.

The Yorktown Bays have evolved into equilibrium embayments over the past fifty years. They are the empirical prototype of much of the research conducted by VIMS on the use of offshore breakwaters for shoreline erosion control (Hardaway *et al.*, 1989; Hardaway *et al.*, 1991; Hardaway and Gunn, 1991; Hardaway *et al.*, 1993; Suh and Hardaway, 1993; and Hardaway and Gunn, 1999). The headlands separating each bay beach are paleo-interfluves with banks approximately +80 ft above MSL composed of shelly marl from the Yorktown Formation (Table 2-1). The headlands were hardened with rock revetments in the early 1960s and reinforced in 1979 (Hardaway *et al.*, 1991).

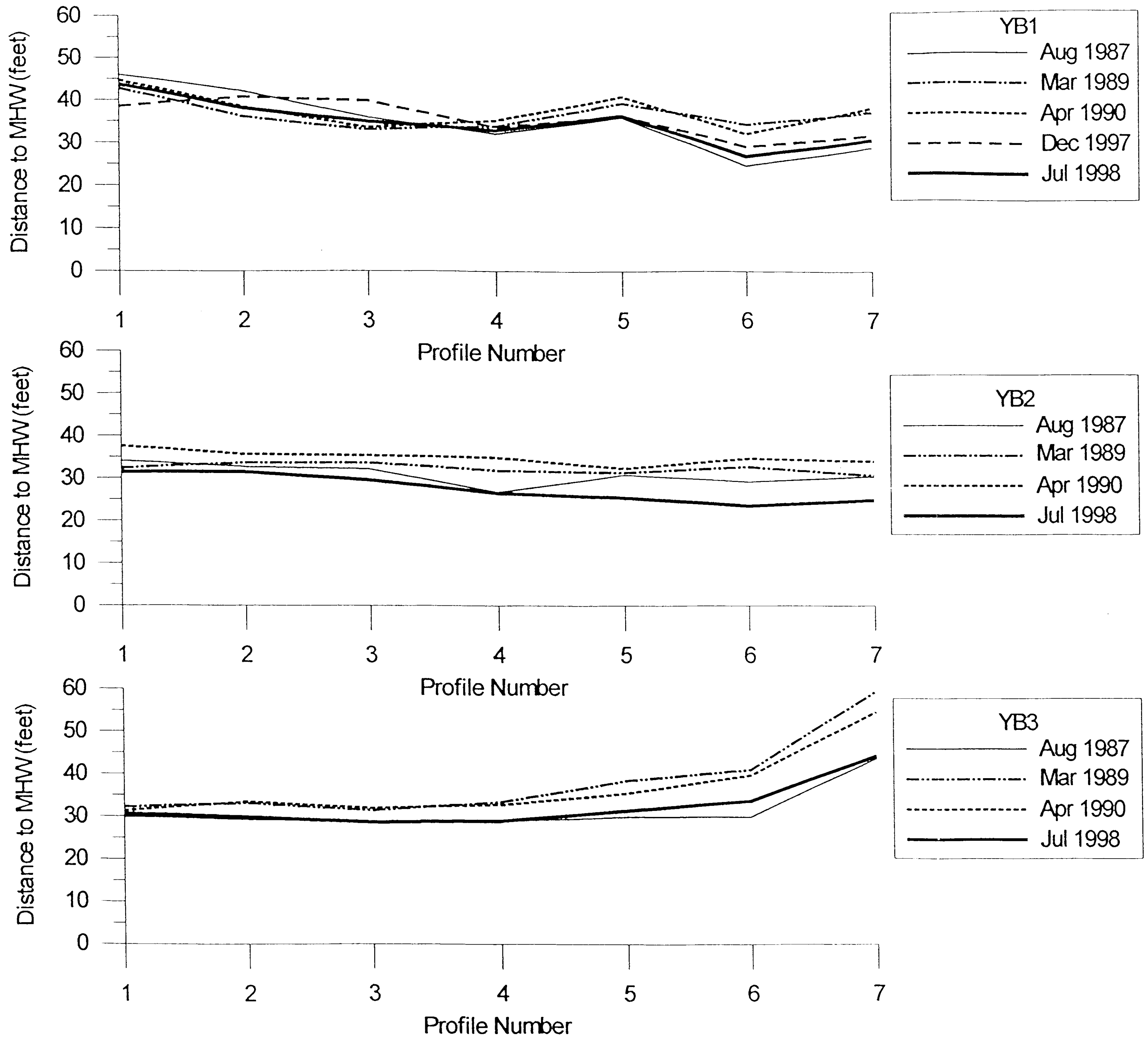
The distance to mean high water (MHW) from the baseline is plotted for several surveys taken at the Yorktown Bay site (Figure 2-6). These distances describe the shape of the beach over time. In general, there has been no net retreat of the shore along these bays in the ten years they have been surveyed. Because the embayments are in a dynamic equilibrium, the sediment moves back and forth along the shore in response to the wave climate. The downriver, or tangential, section of the bays show a loss of material between 1990 and 1998; however, it probably is a result of the seasonal movement of sand away from the tangential section in response to a summer wave climate. Analysis of earlier data (Hardaway *et al.*, 1991) showed that beach sand was shifted to the downriver side of the embayments during northeast storms.

The other site consists of 5 broken concrete breakwaters that were constructed in 1985 just upriver from Yorktown Naval Weapons Station pier (Figure 2-5). The site, called the National Park Service (NPS) breakwaters, was surveyed before and after installation and 2 times per year until 1990. This site was re-occupied and surveyed for this study.

The distance to mean high water (MHW) and distance to the top of bank (TOB) from the baseline is plotted for three surveys taken at the NPS breakwater site (Figure 2-7). The downriver portion of the site has retreated. Breakwaters 4 and 5 have become detached, and while breakwater 5 still slightly influences the wave climate at the site, breakwater 4 has become transparent to waves and does not influence the shape of the shoreline. The bank also has eroded, particularly in response to storms when elevated water levels impact it directly. The NPS breakwaters are still adjusting, by upland erosion, into equilibrium embayments. The breakwaters are only 50 ft long and illustrate that the shorter breakwater units (shorter, relative to the impinging wave length) are less effective than longer structures in maintaining equilibrium embayments.

Figure 2-8 shows the cross-section profiles of the NPS breakwaters through time. The hatching indicates erosion between 1990 and 1997. The stippling shows the erosion between 1997 and 1998, during which time the Twin Northeasters occurred. Limited accretion occurred through time but is not specifically delineated on Figure 2-8. A great deal of erosion occurred along the entire beach profile between 1990 and 1997 even directly behind the breakwaters. However, between 1997 and 1998, much of the erosion occurred above +5 ft MLW indicating that elevated water levels allowed the waves to act directly on the bank.

One interesting feature revealed by analysis of data obtained for Hardaway *et al.* (1991) at the NPS breakwater site is the difference between the beach and upland planforms. The tangential section of the embayed beach between breakwaters generally faces north-northwest and is controlled, in large part, by the northwest wind-generated wave climate. During a typical northeaster, the storm originally has winds blowing from the northeast and elevated water levels, but as the storm moves away from the area, the winds begin to blow from the northwest leaving exposed shorelines orientated into this wind-wave condition. However, when water levels are elevated during northeast storms, the wave action is up against the bank, and the tangential section of the bank planform faces northeast in response to the major component of the storm’s wind-generated wave climate.



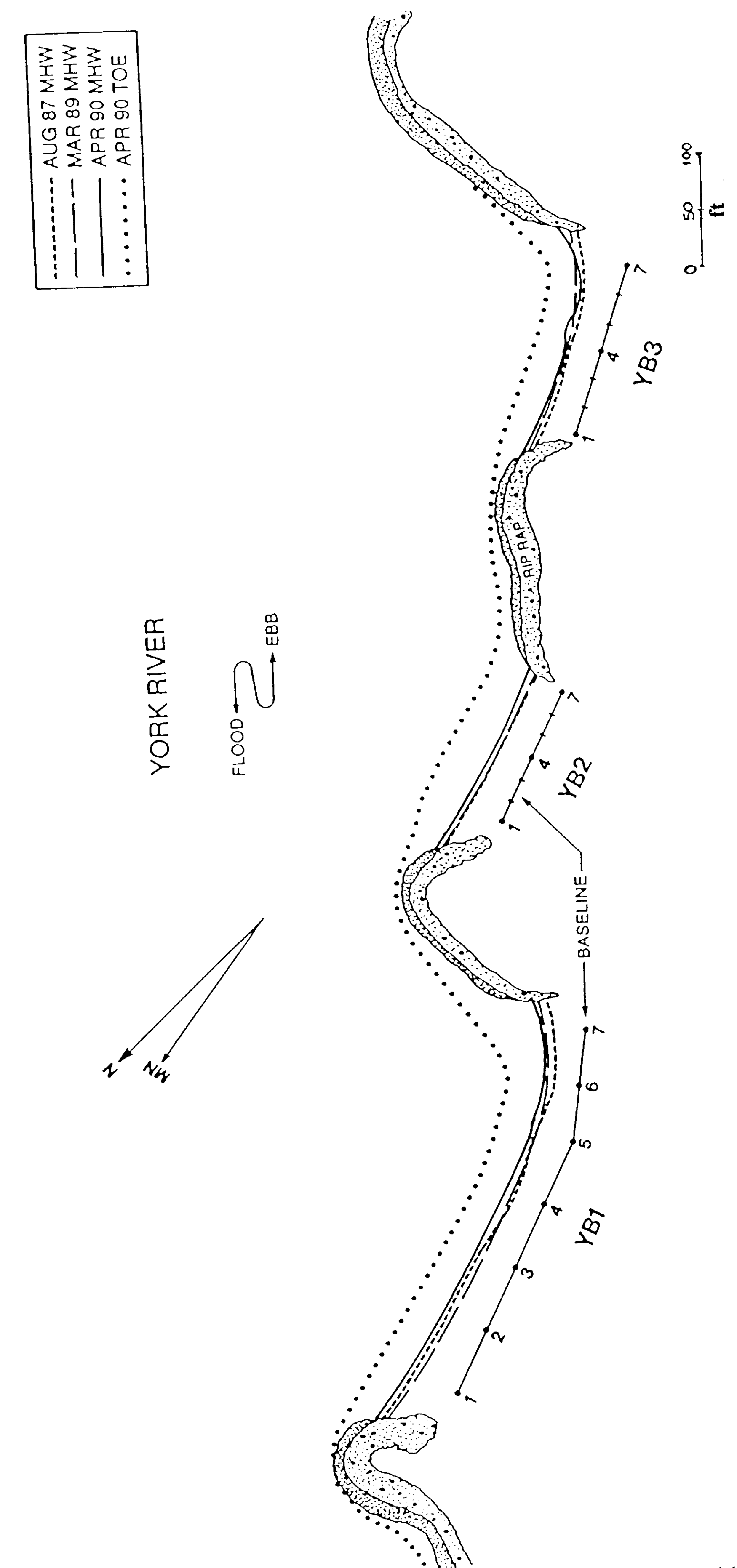


Figure 2-6. Profile baseline and distance to MHW at the Yorktown Bays.

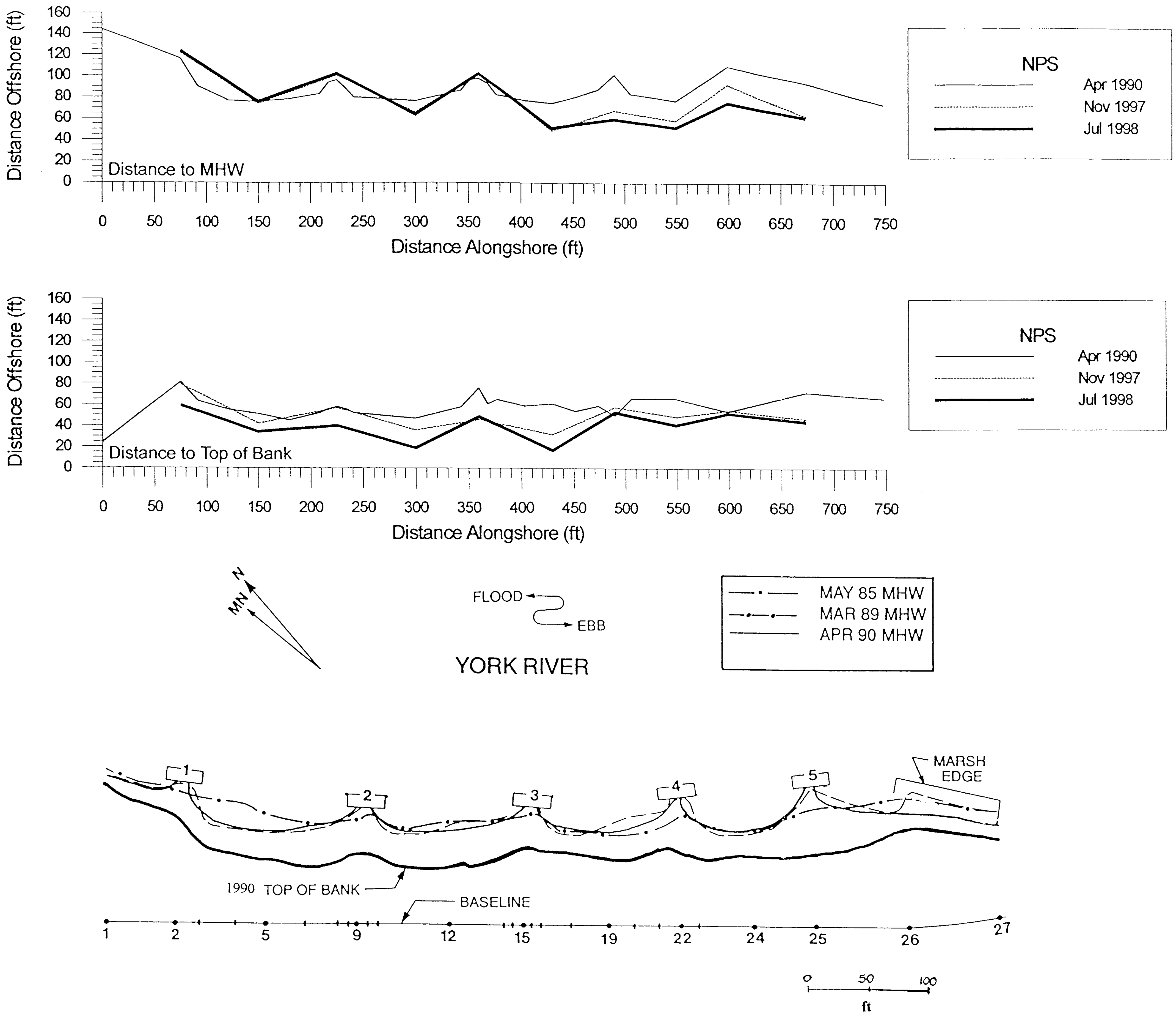


Figure 2-7. Profile baseline and distance to both MHW and top of bank at the National Park Service breakwaters.

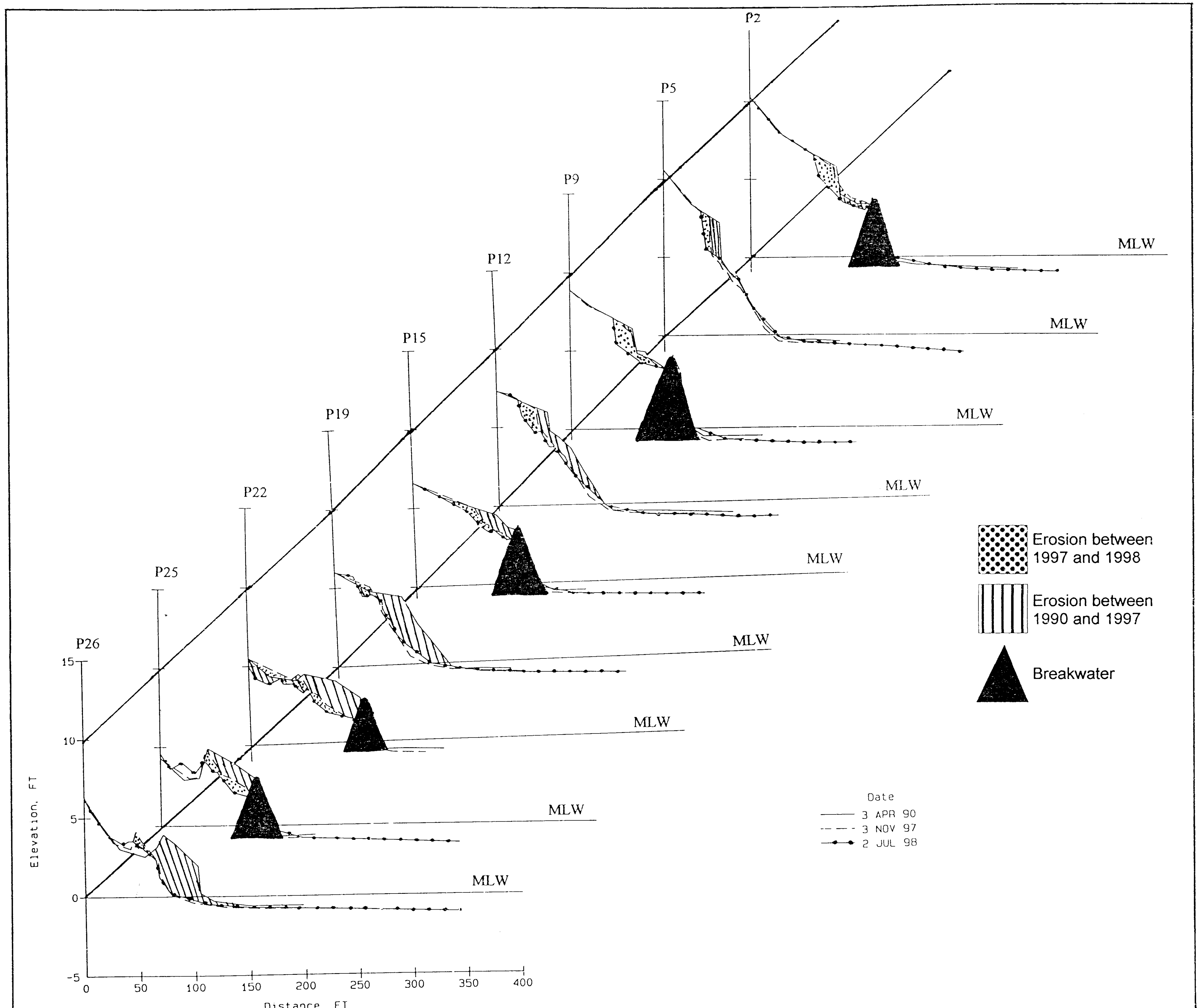


Figure 2-8. Cross-sectional profile change along the shore at the National Park Service breakwater site.

3 ASSESSING ENVIRONMENTAL FRAMEWORK

3.1 Methods Used to Discern Physical Setting

3.1.1 *Reach Boundaries, Archaeology, Historic Shore Change*

The project's shorelines are depicted on five plates and are discussed as chapters that encompass the shore reaches within the study area (Figure 3-1). Reference baselines were created to provide a mechanism for discussion. The four baselines fronting open James River shore (Bathymetric Baselines #1, #2, #4 and #5) correspond to the alongshore axis of the RCPWAVE bathymetric grids (Grids #1-#6) used in the wave climate analysis (discussed in the following section). The shoreline along Powhatan Creek, Back River, Sandy Bay, and The Thorofare have a mid-river reference line (Bathymetric Baseline #3) that will be used for discussion. Segments of shoreline called "reaches" were defined by Byrne and Anderson (1978) and are utilized in this report. The reach numbers for this project, in consecutive order, are 293, 295, 296, 297, 298, 299, 300, 301, 302, 303, 304, 305, 306, and 307; these reaches cover most of the James River shoreline in the study area. Additional reaches designated for this project along Powhatan Creek, Sandy Bay, Back River and The Thorofare are numbered 305A and 305B.

COLO has many cultural resources within the study area since it encompasses most of Jamestown Island which was the site of the first permanent English settlement in North America. The 23-mile Colonial Parkway, which connects Jamestown with Yorktown, provides an aesthetic drive through natural environments with few modern intrusions. Jamestown has one aboveground resources remaining from the original settlement, the ruins of the 1640s church tower, and archaeological sites have been defined for the colonial settlement as well as earlier Native American sites. The archeologic resources of concern identified in the Plan are within 100 ft of the shoreline and include Sites 1, 3, 4, 8, 10, 11, 14, 18, 19, 25, 30, 31, 33, 35, 38, 39, 43, 46, 47, 48, 50, 51, 52, 55, 57, and 58 (Table 3-1). Sites numbered 1, 10 (Black Point), 30, 31, 51, 52, and 55 are considered of high value in terms of Archaic and Colonial artifacts (Dennis Blanton, *pers. comm.*). New Towne, which has no designated site number, also is considered a critical area. The Colonial Parkway runs through the ruins of a Confederate Fort near College Creek. Little is known about the Fort, but it has been deemed an archaeological area of concern since part of the Fort already has eroded. Each Site will be treated individually later in the report within the plate chapter in which they fall.

Four shorelines were plotted for the entire study area. Physical survey dates varied for sections of the shoreline resulting in the plotting of the following dates: 1874, 1942 and 1952 (1942/52), 1979 and 1983 (1979/83), and 1990. To track changes in shore trends, the rate of change between two different shoreline dates were determined. The shore positions for each date were determined perpendicular to the bathymetric baselines every 200 ft along shore. From this data, the rate of change in shore position, in ft/yr, was calculated to describe the net change of the shoreline during the time interval. The short time span between 1980 and 1990 tends to exaggerate trends in shore change.

3.1.2 *Upland Bank and Shore Zone Characteristics*

The shoreline on Jamestown Island is comprised of eroding marsh and uplands. Much of the Jamestown town site has been protected by shore erosion control structures. There is a long beach zone along the southwest shore of the Island that has accreted since the mid-1800s. Another beach zone occurs along much of the Colonial Parkway that borders the James River. The building of the Parkway in the mid-1950s provided much of the material for this beach.

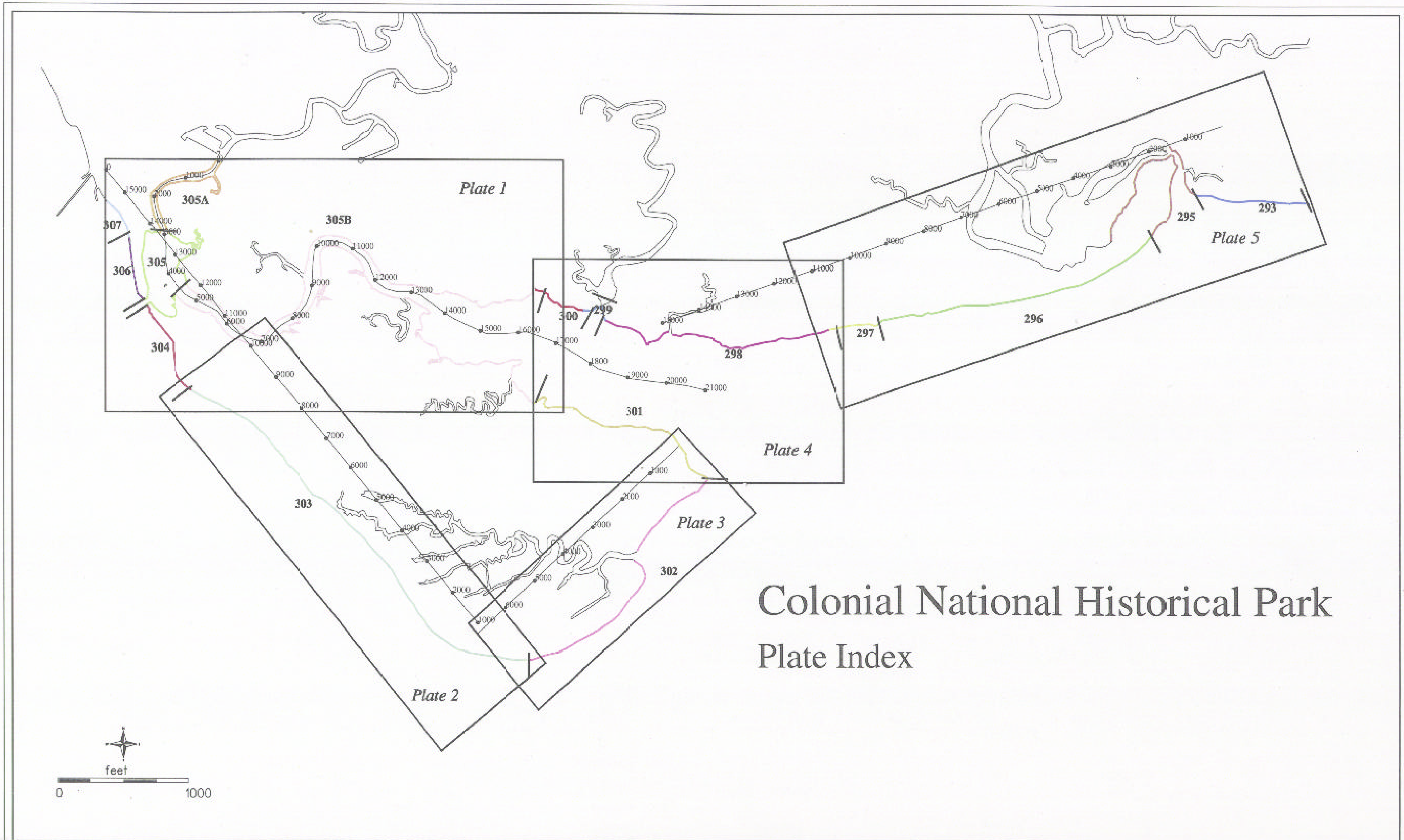
Another element in the analysis of shoreline conditions is an inventory of recent historical land use patterns and shoreline conditions. Aerial video imagery taken in 1993 was compared to newly-acquired 1997 aerial video. Oblique, aerial slides taken in 1974 also were used to determine land use and shore zone conditions. Shoreline and land use characteristics were transcribed onto a 1979 topographic map of the project shorelines using a coding system developed at VIMS (Table 1-1). The data were transferred digitally into Arc/View, a GIS database program.

To simplify the resulting database for graphic display, the coding system was reduced to six shoreline attributes and seven land use categories, bolded in Table 1-1 and as shown on the individual reach assessment plots in the following chapters. On the plots, the codes are depicted with a colored line for each reach. The codes for riprap and bulkhead were combined to one category labeled hardened. Shoreline attributes refer to the general condition of the shoreline and/or what shore structures are present. The primary land use within 100 ft of the shoreline is the basis for the land use attributes. Land use generally is limited to unmanaged wooded and nonwooded land. Nonwooded areas usually correspond to marsh shorelines, particularly around Jamestown Island. Open fields are more frequent along the Colonial Parkway approach routes. Since no change occurred in land use patterns between 1993 and 1997 within the study area, this is shown as one line on the reach assessment plots.

In order to rank shorelines in the overall management plan three types of areas of concern were defined. **Lesser Areas of Concern (LAOC)** include eroding upland areas with no archaeological sites or eroding marsh sites that are very near breaching which then would expose the adjacent upland to more frequent wave actively. **Areas of concern (AOC)** are eroding shorelines that threaten infrastructure and/or archaeological resources. **Critical Areas of Concern (CAOC)** are located where very sensitive archaeological resources areas threatened by erosion. The sites of archaeological significance generally occur on the uplands and ridges around Jamestown Island.

Table 3-1. Listing of archaeological sites of concern for the COLO Shoreline Management Plan.

Location	COLO Shoreline Management Plan Site Number	Blanton and Kandle (1997) Site Number	Plate Number	Reach Number	Research Priorty
Back River	47	44JC932	1	305B	Low
	43	44JC928	1	305B	Moderate
	25	44JC914	1	305B	Moderate
	50	44JC935	1	305B	
The Thorofare	30	44JC915	1	305B	Very High
	31	44JC916	1	305B	High
	48	44JC933	1	305B	
	18	44JC903	4	301	Highest
	14	44JC899	4	301	
	4	44JC889	4	301	High
	3	44JC888	4	301	
	1	44JC886	4	301	High
	19	44JC904	4	301	
Black Point	10	44JC895	3	302	Highest
	8	44JC893	3	302	Low
	11	44JC896	3	302	Low
Lower Point	58	44JC943	3	302	Moderate
	35	44JC920	2	303	Very High
	51	44JC936	2	303	Low
Goose Hill	52	44JC937	2	303	High
	55	44JC940	2	303	Moderate
	57	44JC942	2	303	Low
	33	44JC918	2	303	
	38	44JC923	2	303	Moderate
	39	44JC924	2	303	Low
Church Point	46	44JC931	1	304	Moderate



Colonial National Historical Park

Plate Index

Figure 3–1. Plate index for the COLO Shoreline Management Plan

3.1.3 Nearshore and Channel Characteristics

The nearshore region within the project area varies in extent and bathymetry. Along the James River's shoreline, the nearshore "shelf" from the shoreline to about the -12 ft MLW isobath varies in width from a maximum of about 4,500 ft east of Black Point to about 100 ft off Lower Point and about 400 ft off Church Point and the town site. The Thorofare has a maximum depth of 6 ft MLW which occurs in a narrow channel into the Back River. The Back River averages about 200 ft wide with narrow nearshore regions that drop quickly into the tidal channel thalweg which reaches depths of 18 ft around Pyping Point.

The Back River becomes Sandy Bay as one proceeds NW. Sandy Bay is about 1,000 ft wide, and its depths average about 5 ft MLW. Sandy Bay narrows into Powhatan Creek which turns north and flows under the Colonial Parkway. Powhatan Creek averages 100 ft wide, has a very narrow nearshore, and the thalweg depth averages 5 ft MLW. Powhatan Creek, Sandy Bay and Back River are meandering tidal channels whose shorelines are dominated by boat wake and tidal currents rather than wind-driven, wave action like The Thorofare and James River shorelines.

Generally, there are no significant marine resources, such as SAV, oysters, and clams, in the nearshore within the project limits. Anthropogenic impacts to the nearshore region have been significant and include the building of the Jamestown Isthmus and Colonial Parkway. These projects placed large quantities of fill across the nearshore and tidal bottom. These projects also altered the tidal channels around Sandy Bay and College Creek. The disposal of dredge material (Figure 3-2) from nearby navigation channels also has modified the nearshore in those areas including a small area in Sandy Bay and a larger disposal site along the southeast James River shore of Jamestown Island (U.S. Army Corps of Engineers, Unknown). Other impacts to the nearshore involve the building to the Ferry Pier and the wharf at Jamestown Settlement both of which are upriver from Jamestown Island. These structures significantly reduce the amount of littoral sands available from upriver sources.

3.2 Methods Used to Discern Hydrodynamic Setting

3.2.1 Wave Climate Assessment

3.2.1.1 General Statements

The wave climate is the overall wave energy that impacts the project shoreline averaged through time. The wave climate along any given shoreline is a function of fetch and nearshore bathymetry. <u>Fetch</u> is defined as the distance over water that wind can blow and generate waves and is determined by procedures outlined in U.S. Army Corps of Engineers (1984). The direction a shore faces also is important because in the Chesapeake Bay estuarine system the northerly-facing shorelines have historic erosion rates more that twice the south-facing shorelines (Hardaway and Anderson, 1980). The natural processes which drive sediment along the shoreline can vary considerably due to the wave climate. The wave climate also varies along shore as deep water waves are affected by the complex nearshore bathymetry they travel across altering their height and direction of propagation. Modifications to the waves occur through the processes of shoaling, refraction, diffraction, and loss of wave energy by frictional dissipation by interaction with the bottom.

As deep water waves move into shallower water, they begin to "feel bottom" or shoal. The wave length and speed decrease while the height increases. Only the wave period remains the same. In addition to wave attenuation, the waves refract. The part of the wave advancing in shallower water moves more slowly than that part is still advancing in deeper water; this causes the wave crest to bend toward alignment with the underwater contours, or refract, so that upon breaking the waves are nearly parallel to the shoreline when they reach the beach. However, irregular bottom topography can cause waves to be refract in complex ways and produce variations in wave height and energy along the coast (Komar, 1976).

Wave refraction can cause either a divergence or convergence of wave energy (Figure 3-3). Over parallel, nearshore contours, refraction produces an increasing distance

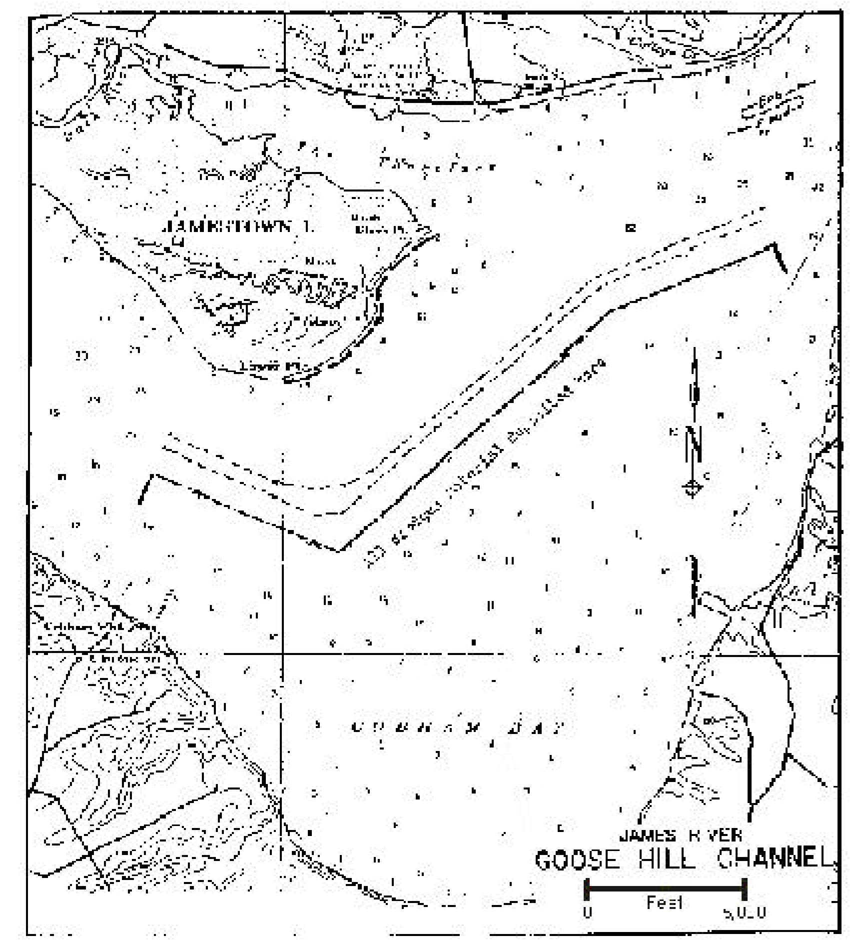


Figure 3-2. Nearshore bathymetric chart locating the placement of fill material (U.S. Army Corps of Engineers, Unknown).

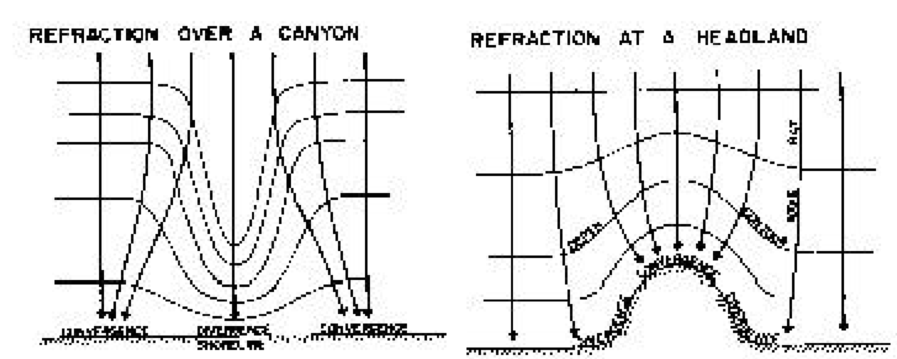


Figure 3-3. Convergence and divergence of wave rays resulting from wave refraction (Komar, 1976).

between wave orthogonals or rays in the direction of travel (divergence). This causes a decrease in wave height and energy concentration. Convergence occurs when wave orthogonals focus along a section of shoreline and creates larger wave heights and increases energy concentration along the shore. A depression in the bottom can cause waves to diverge while the wave rays on either side of the "hole" converge (Figure 3-3). Waves also bend and refract toward headlands because of the offshore shoal often associated with the headland. The wave energy is concentrated on the headland and the wave heights there may be larger than those in the adjacent embayment (Komar, 1976). Diffraction of waves occurs when part of a train of waves is interrupted by a barrier, such as a breakwater. Energy is transmitted laterally along the wave crest, the effect of which is that waves will bend into the sheltered region behind the structure.

3.2.1.2 Numerical and Empirical Modeling

A numerical computer model is used to determine the modifications to incident waves by refraction, diffraction, shoaling, and frictional dissipation. The model quantifies changes in wave height, direction, and energy along the shoreline. Six numerical grids were created to encompass the study area including the shoreline and the nearshore bathymetry (Figure 3-4). Grids #1 and #2 are on the James River shoreline along Jamestown Island. Grids #5 and #6 are in the same location but have a different orientation in order to model the impact of northwest waves along this shore reach. Grid #3 encompasses Lower Point to Black Point and Grid #4 is the James River's shore along the Colonial Parkway.

Wind/wave modeling utilized the SMB and RCPWAVE computer models. SMB generates a predicted wave height and period based on the effective fetch and offshore bathymetry of a site. RCPWAVE is a linear wave propagation model designed for engineering applications. This model, originally developed by the U.S. Army Corps of Engineers (Ebersole *et al.*, 1986), computes changes in wave characteristics that result naturally from refraction, shoaling, and diffraction over complex shoreface topography. To this fundamentally linear-theory-based model, oceanographers at VIMS have added routines which employ wave bottom boundary layer theory to estimate wave energy dissipation due to bottom friction (Wright *et al.*, 1987). RCPWAVE assumes that only the offshore bathymetry affects wave transformation; it does not include the effects of tidal currents.

RCPWAVE takes an incident wave condition, which has been generated by the SMB model, at the seaward boundary of the grid and allows it to propagate shoreward across the nearshore bathymetry. As the wave moves across the irregular bottom topography, the model computes changes in wave height and direction as well as wave energy dissipation due to refraction, diffraction, and shoaling. Frictional dissipation due to bottom roughness also is accounted for in the analysis and is relative, in part, to the mean grain size of the bottom. Appendix 3 discusses the methods used to assess the wave climate for the Plan.

Utilizing the output from the RCPWAVE model as input to the Static Equilibrium Bay (SEB) model, the equilibrium planforms between structures can be determined. Beach planform calculations use the annual significant wind-generated wave approach direction and selected design storm conditions. This procedure was first developed by Silvester (1970) and later refined by Hsu *et al.* (1989) and Silvester and Hsu (1993). Their methods were developed along open-ocean, coastal embayments usually influenced by a unidirectional, significant annual wave field. In Chesapeake Bay, there often is a bimodal annual wind field that generates a bimodal wave climate that must be accounted for in beach planform design. This sometimes results in embayments with two tangential beach sections at any one time as beach planforms from one wind-generated wave field replaces or resides with another. Figure 3-5 shows the relationship of the 3 procedures in beach planform design, 1) SMB, 2) RCPWAVE, and 3) SEB. This 3-step procedure is effective in predicting bay shape for design purposes.

The wind field diagram for a typical bay site (Figure 3-5) depicts the direction of the annual significant wind and the design storm wind. Wave height (H) and period (T) are predicted at a point offshore of the project site by SMB. The wind and wave directions are assumed to be the same. SMB output is used for input to RCPWAVE and the associated bathymetric grid. RCPWAVE models wave attenuation across the nearshore region. The output wave height and approach angle (H and α) are chosen at the appropriate area of the proposed breakwater project. Wave angle drives the beach planform calculations from SEB. The upper beach berm is modified by the design storm condition.

The relationship between four specific headland breakwater system parameters were investigated by Hardaway *et al.* (1991) and Hardaway and Gunn (1991) for 35 breakwater embayments around Chesapeake Bay. Referring to Figure 3-5, these parameters include breakwater crest length, (L_B), gap between breakwaters (G_B), backshore beach width (B_m) and embayment indentation (M_b). The mid-bay backshore beach width and backshore elevation are important design parameters because they determine the size of the minimum protective beach zone in the headland breakwater system. This beach dimension often drives the bayward encroachment that is required for a particular shore protection design. Linear regression analyses were best for the relationship of M_b vs. G_B with a correlation coefficient of 0.892. The ratio of these two parameters is about 1:1.65 and can be used as a general guide in siting the breakwater system for preliminary analysis. Then, detailed bay shape using the SEB can be done. Stable relationships for M_b and G_B are not valid for transitional bay/breakwater segments that interface the main headland breakwater system with adjacent shores.

Storms are a large part of the force of change along COLO's James River and The Thorofare shorelines. Two types of storms can impact the shore — hurricanes and northeasters. During a hurricane, storm surges, which can exceed 16 feet on the open coast, and high winds can transport large amounts of sediments. Northeasters have weaker wind fields and generally have surges less than 7 feet. However, these extratropical northeasters usually have longer durations and can span several tidal cycles significantly elevating water level during times of high tide.

Tides and tidal currents have an impact on wind/waves and sediment movement along the project shorelines. The mean tide range at Jamestown Island is 2.0 ft with a spring tide range of 2.4 ft (NOAA, 1989). Chen (1978) modeled the tidal currents in the James River. He found relatively large tidal currents running along Lower Point in both the ebb and flood direction.

Modal waves are the annual, average conditions impacting a given shore reach. For this project, there are two or three significant fetch exposures for each grid and associated shore segments. Storm wave parameters are hindcast from estimated winds, outside the wind table, that might occur during low-frequency, elevated water levels (*i.e.* storm surge). Modal wave conditions operate almost exclusively on the beach and intertidal zone under normal or seasonal water levels. Modal wave conditions also provide the somewhat constant undercutting associated with marsh peat erosion. During storms, the undercut peat mats are torn off and deposited in the nearshore to be "dissolved" by waves and currents. The largest rates of shore erosion occur during storms when the sediment transport system responds to storm surge levels, wind direction, intensity and duration.

3.2.2 Littoral Processes

This element of the discussions describe the impact of hydrodynamic forces (waves, currents, and tides) on the material resistance of the land and nearshore substrate. The patterns of erosion and net direction and rate of sediment transport are critical elements in understanding the process of shoreline change as well as in the development of shoreline management strategies.

There are four important bank/shore types in the scheme of shoreline erosion around Jamestown Island and along the Colonial Parkway: beaches/spits, upland banks, marsh fringe, and protected shorelines. The geomorphic evolution of estuarine shorelines is an interplay among these four features. They create differentially eroding shorelines which allow us to better ascertain the impinging wave climate by identifying the tangential bank and/or beach features. Tangential features, as noted previously, wave climate, shore change analysis as well as the description of offsets in bank and marsh shores created by differential erosion allow us to develop a fairly accurate picture of <u>how</u> the shoreline has evolved through time.

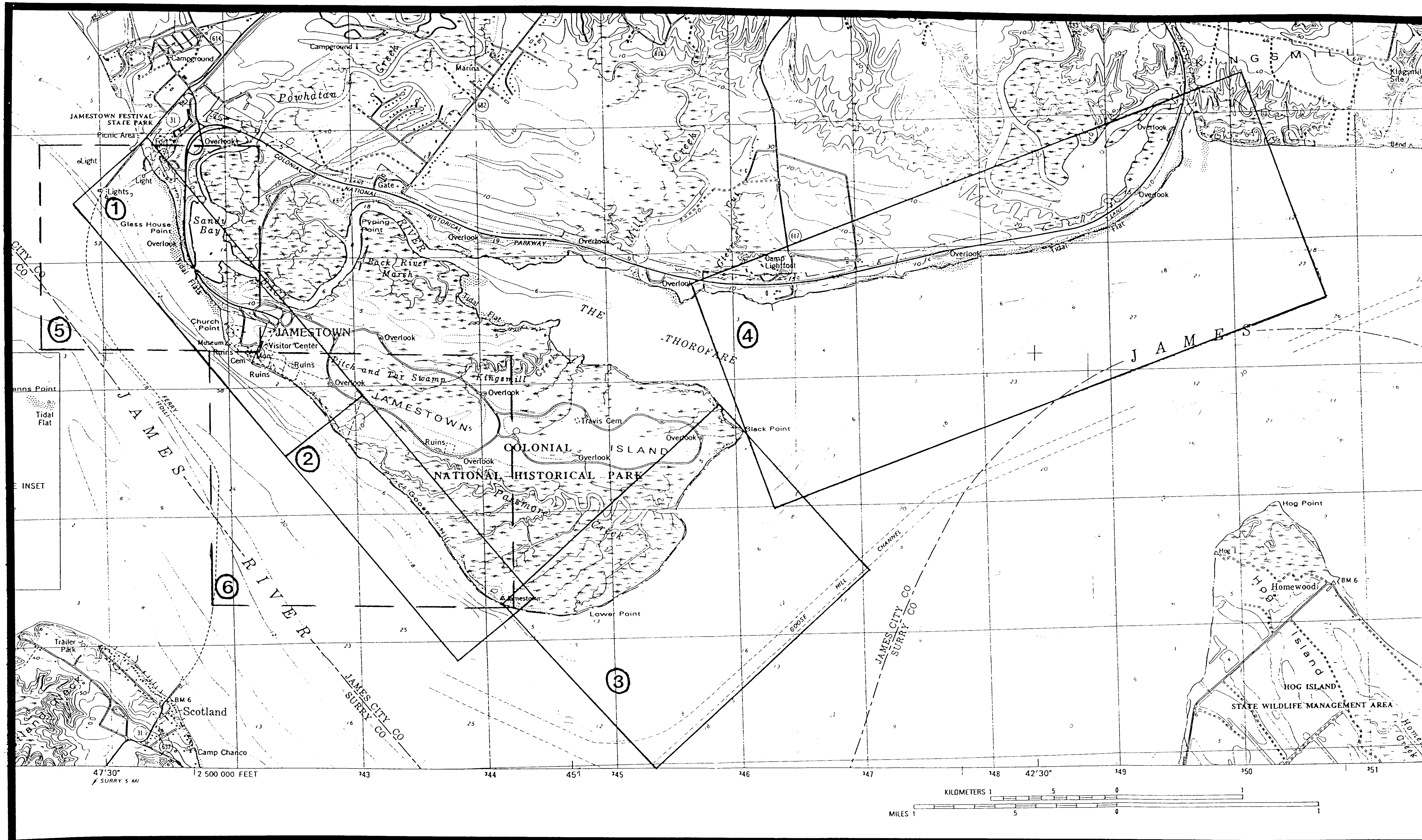


Figure 3-4. Location of the six bathymetric grids created for the RCPWAVE analysis.

In order to determine the rate and direction of transport along the shoreline, the output of the RCPWAVE analysis was used. The breaking wave height and its angle to the shore were exported from each RCPWAVE output file. These data were used to calculate the rate of longshore transport along the shoreline utilizing the CERC formula as described in the Shore Protection Manual (U.S. Army Corps of Engineers, 1984). The transport rates were mean-weighed with the 30 years of wind data in order to determine the net direction of sediment transport. Transport formulas have a $\pm$ 50% accuracy rate so the actual longshore transport rates determined in this effort should only be used as a guide and not as an absolute. The direction of transport is much more reliable. Overall, this analysis, in conjunction with the reading of morphologic features, can provide an accurate description of the littoral transport system of the site. Results of this analysis are presented in the Plate chapters, and a more detailed description of the process is in Appendix 3.

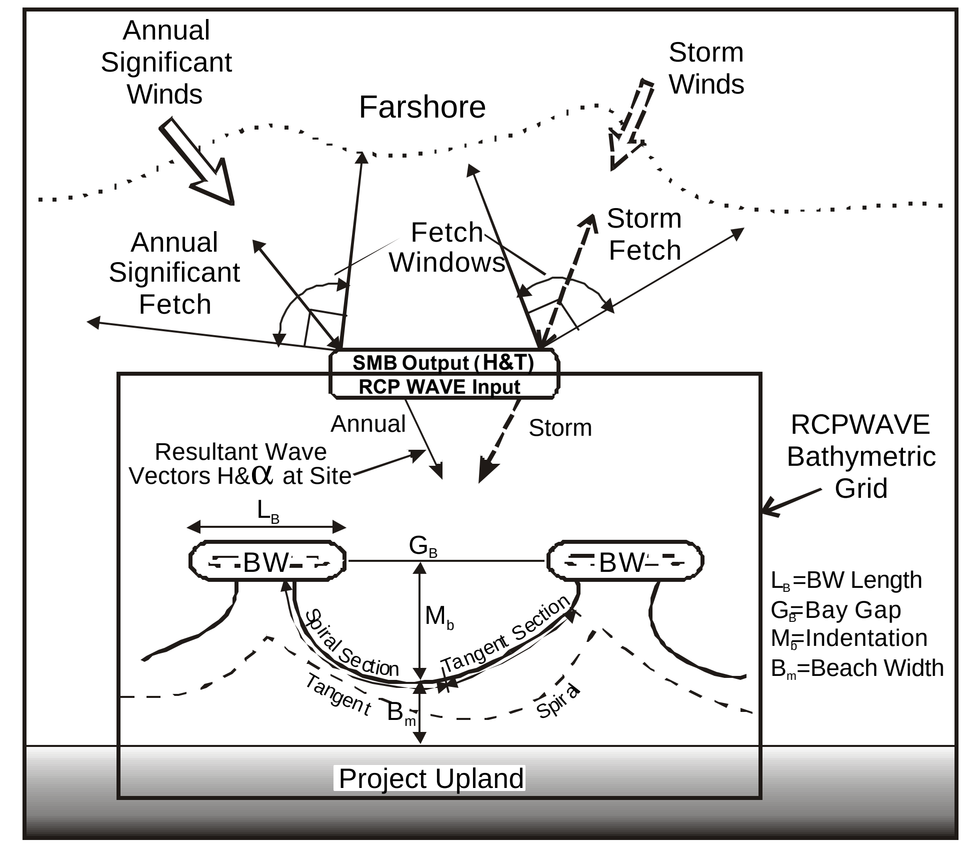


Figure 3-5. Parameters related to wind-generated wave conditions (SMB), nearshore wave refraction (RCPWAVE), and beach planform prediction (SEB).

4 SHORELINE MANAGEMENT ELEMENTS

4.1 Objectives

The first step in developing a framework for shoreline management is establishing clear objectives toward which erosion control strategies can be directed. In developing this Shoreline Management Plan, the following objectives have been given consideration:

- Prevention of loss of land and protection upland improvement.
- Protection, maintenance, enhancement and/or creation of wetlands habitat both vegetated and non-vegetated.
- Management of upland runoff and groundwater flow through the maintenance of vegetated wetland fringes.
- For a proposed shoreline strategy, addressing potential secondary impacts within the reach which may include impacts to downdrift shores through a reduction in the sand supply or the encroachment of structures onto subaqueous land and wetlands.
- Providing access and/or creation of recreational opportunities such as beach areas.
- For Jamestown and environs, a proposed shoreline strategy should not interfere with historical interpretation.

These objectives must be assessed in the context of a shoreline reach. While all objectives should be considered, each one will not carry equal weight. In fact, satisfaction of all objectives for any given reach is not likely as some may be mutually exclusive. Meetings and field trips with COLO personnel and Dennis Blanton identified areas of archeological concern along the shoreline. These areas of concern could then be addressed specifically in the shore change and hydrodynamic analysis.

It is the intention of this study to develop shoreline management schemes for Jamestown by controlling or hardening points along the shoreline and allowing much of the adjacent shoreline to evolve (through continued erosion) to equilibrium planforms. This would most likely entail a phased approach by addressing major points and areas of critical erosion first.

4.2 Protection Strategies

Four general shore protection strategies have been considered in the discussion of each shore reach within the study area.

4.2.1 No Action

Essentially, this strategy allows the natural processes of shoreline erosion and evolution to continue as they have for the past 15,000 years as part of the latest sea-level transgression.

4.2.2 Defensive Approach

The Defensive Approach refers to the use of shore protection structures that commonly are placed along the base of an eroding bank as a "last line of defense" against the erosive forces of wave action, storm surge, and currents. For the purposes of this study, stone revetments are the strategy employed.

4.2.3 Offensive Approach

The Offensive Approach to shoreline protection refers to structures that are built in the region of sand transport to address impinging waves before they reach upland areas. These structures traditionally have been groins, but over the past decade, the use of breakwaters has become an important element for shoreline protection. For this study, stone breakwaters and sills will be the strategies employed. Spurs are installed on breakwaters and sills to move the wave diffraction point further offshore to assist in attaining local equilibrium of the shore planform. The use of offensive structures requires a thorough understanding of littoral processes acting within a given shore reach.

4.2.4 Headland Control

Headland control is an innovative approach to shoreline erosion protection because it addresses long stretches of shoreline and can be phased over time. The basic premise is that by controlling existing points of land (*i.e.* headlands) or strategically creating new points of land, the shape of the adjacent embayments can be predicted. A thorough understanding of the littoral processes operating within the reach is necessary to create a stable planform. Headland control can utilize elements of the three previous strategies.

4.3 Coastal Structures

4.3.1 General

A variety of coastal structures can be employed as part of an overall erosion control strategy. A brief description of each type of structure and its schematic diagram are provided in the following paragraphs and figures. The optimum plan will achieve a balance between long-term, predictable shore protection and cost.

<u>Revetments</u> are shoreline armoring systems that protect the base of eroding upland banks and usually are built across a graded slope (Figure 4-1-1 and Figure 4-1-2). The dimensions of the revetment are dependent on bank conditions and design parameters such as storm surge and wave height. These parameters also determine the size of the rock required for long-term structural integrity. Generally, two layers of armor stone are laid over a bedding stone layer with filter cloth between the earth subgrade and bedding layer.

<u>Breakwaters</u> and <u>sills</u> are "free standing" structures designed to reduce wave action by attenuation, refraction, and diffraction before it reaches the upland region. A sill (Figure 4-2-1 and Figure 4-2-2) has a lower crest, is closer to shore, and usually is more continuous than larger breakwater units that the sill can be used in combination with. Sills are installed with beach fill to create a substrate for establishing a marsh fringe.

Attached or headland breakwaters usually require beach fill in order to acquire long-term shoreline erosion control (Figure 4-3-1 and Figure 4-3-2) since they are constructed in areas that are subject to more energetic conditions. Headland breakwaters can be used to accentuate existing shore features and are the be a primary component for Headland Control. The dimensions of a breakwater system are dependent on the desired degree of protection and potential impacts on littoral processes.

<u>Spurs</u> are similar to breakwaters and sills in that they are "free standing" structures. The distinction is that spurs are attached to the shoreline or another structure; the unattached end of the spur acts as a breakwater by diffracting incoming waves.

<u>Headland Control</u> can be accomplished with the aforementioned structures and usually involves protecting a point or shore headland (Figure 4-4-1 and Figure 4-4-2). This strategy partially protects long reaches of shoreline since littoral sands are encapsulated to create a beach and impinging waves are redirected so that they have less impact alongshore. By providing a strategic hard point, adjacent shorelines are allowed to erode into equilibrium planforms. Predicted, stable shore planforms between proposed headland structures are provided for recommended shoreline strategies of each reach. These planforms are estimates based on general wave climatology and shoreline composition (*i.e.* marsh, upland).

4.3.2 Structures for COLO Shoreline Management Plan

The following cross-sections represent the four specific shoreline strategies that are recommended for the project shorelines. Figure 4-5-1 is a cross-section of a typical sill that is recommended in the Plan. Two designs are shown in Figure 4-5-1. The first size has a crest elevation of +3 ft MLW (IA), and the second has a crest elevation of +3.5 ft MLW (IB). The second design (II) is a typical breakwater recommended for the marsh shore on the James River (Figure 4-5-2). It has a crest elevation of +3.5 ft MLW and a width of 8 ft. The third structure depicted (III) is a typical low-crested breakwater that would be utilized along Jamestown Island shores. It has a crest elevation of +3 ft MLW and a crest width of 10 ft (Figure 4-5-3). The fourth structure recommended in the Plan is a typical breakwater that could be utilized along the James River, particularly along the Colonial Parkway (Figure 4-5-4). There are two different sizes of structure IV. Both structures require beach fill and are 8 ft wide, but type IVA has a crest elevation of +4 ft MLW while IVB has a crest elevation of +5 ft MLW.

Each Plate chapter will discuss the use of the four basic methods of shore management. In addition, recommendations will be made regarding which type of structure is suitable for that particular reach. The type of structure will be denoted by the Roman numeral and letter where appropriate. A summary of all structures along with cost estimates is presented at the end of this report.

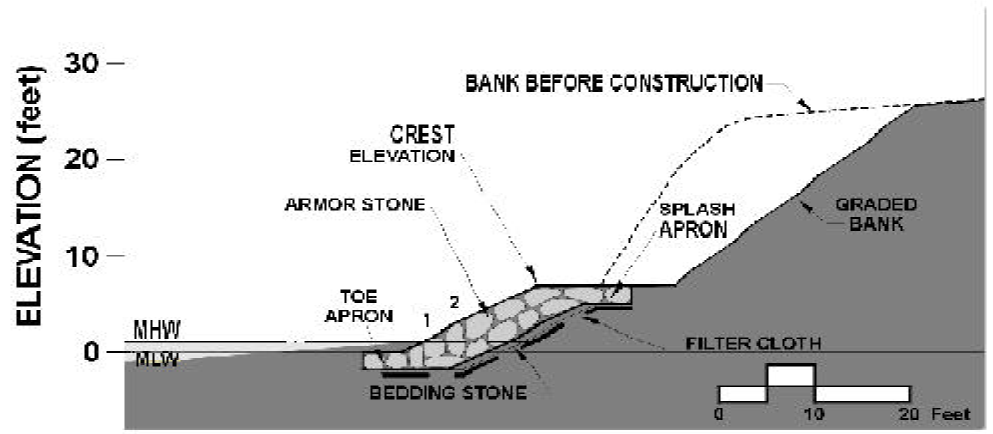


Figure 4-1-1. Cross-section of a typical revetment.

Figure 4-1-2. Stone revetment shortly after construction on the Potomac River, Va.

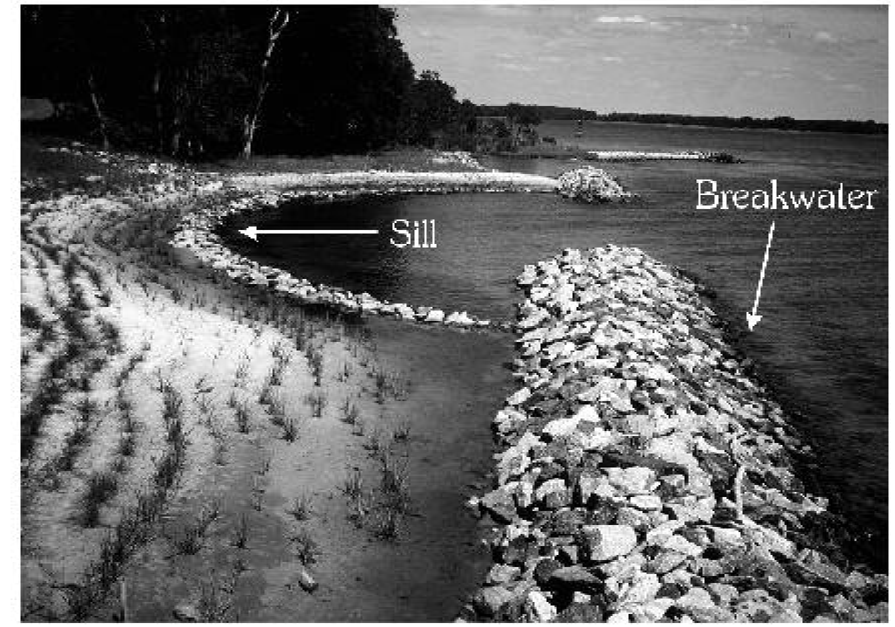


Figure 4-2-1. Stone sill with connecting breakwaters, sand fill, and marsh implantation on the Choptank River, Talbot County, Maryland shortly after construction.

Figure 4-2-2. Stone sill and breakwater project after 5 years.

After Hardaway and Byrne, 1999

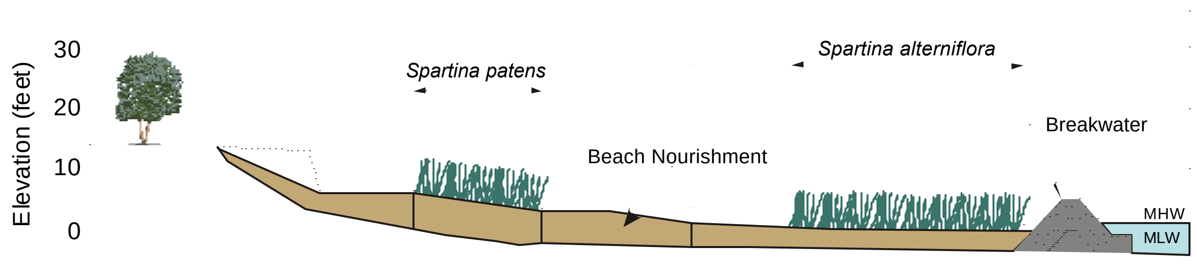


Figure 4-3-1. Typical breakwater cross-section.

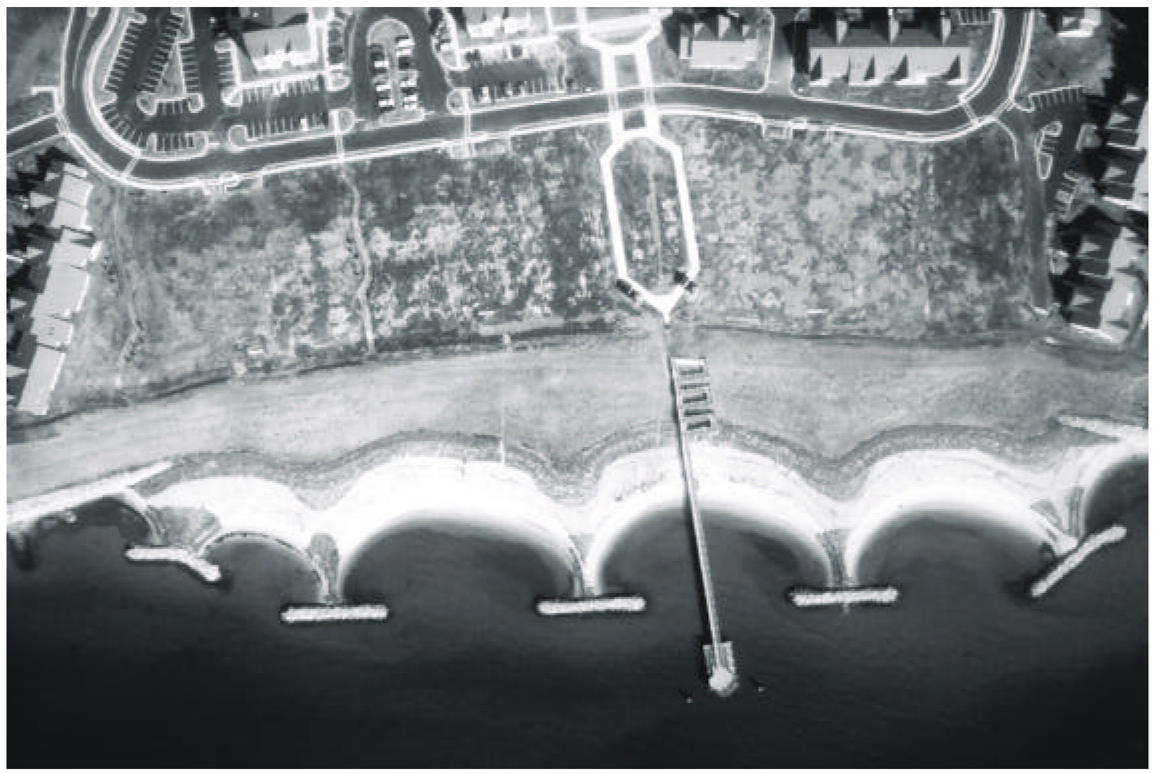


Figure 4-3-2. Breakwater system on Patuxent River in Calvert County, Md.

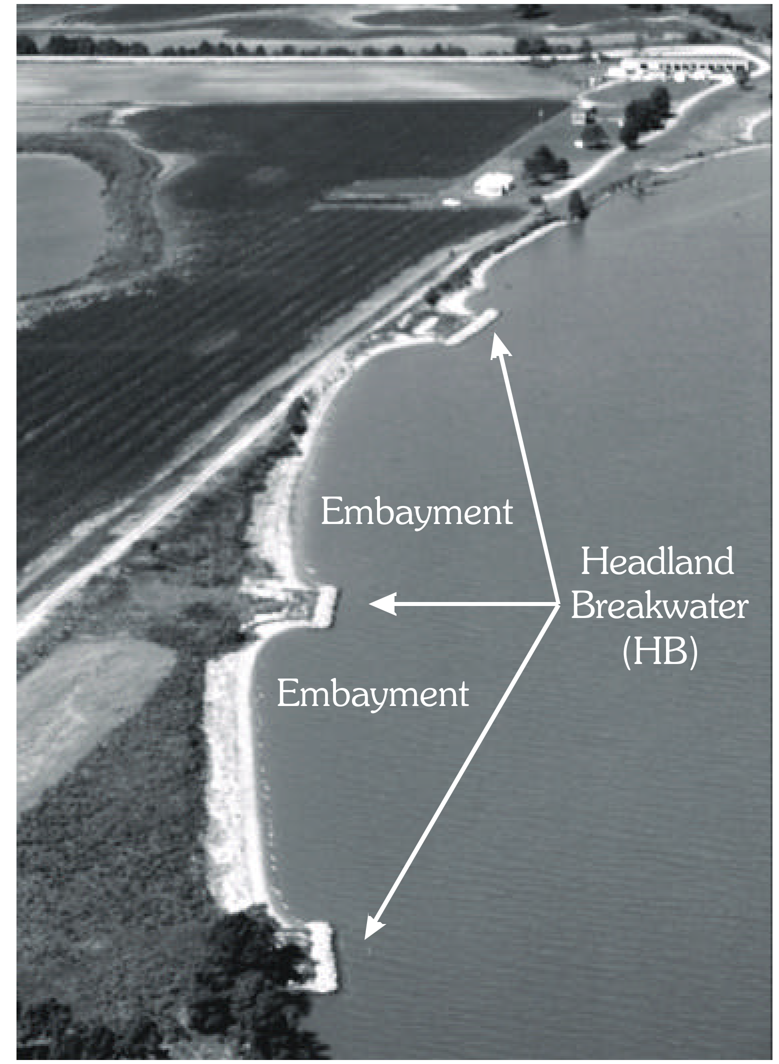


Figure 4-4-1. Headland control systems installed in 1998 at Hog Island, James River, Virginia.

Figure 4-4-2. Headland control systems installed in 1998 in Westmoreland Co., Virginia in Potomac River.

After Hardaway and Byrne, 1999

I

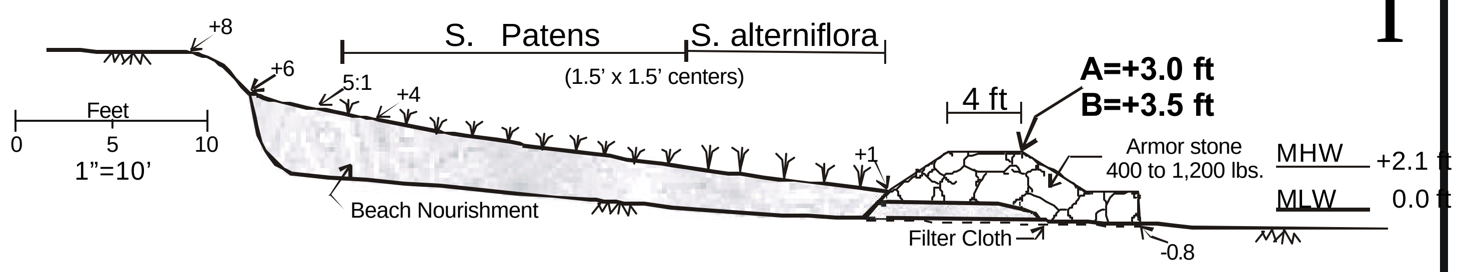


Figure 4-5-1. Recommended sill for Back River and The Thorofare.

II

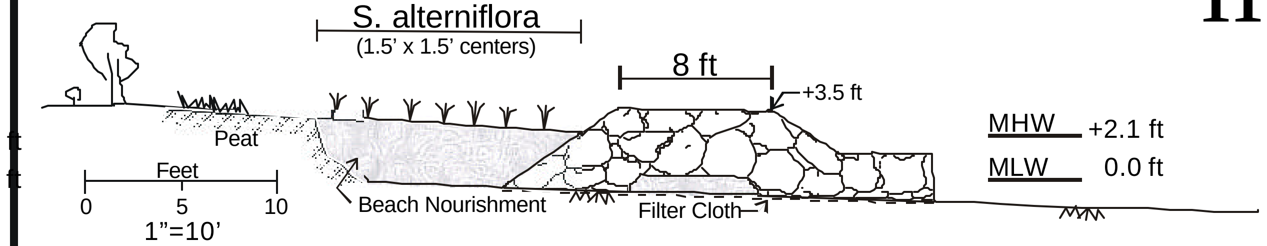


Figure 4-5-2. Recommended low crested (reef) breakwater for Jamestown Island's James River marsh shore.

III

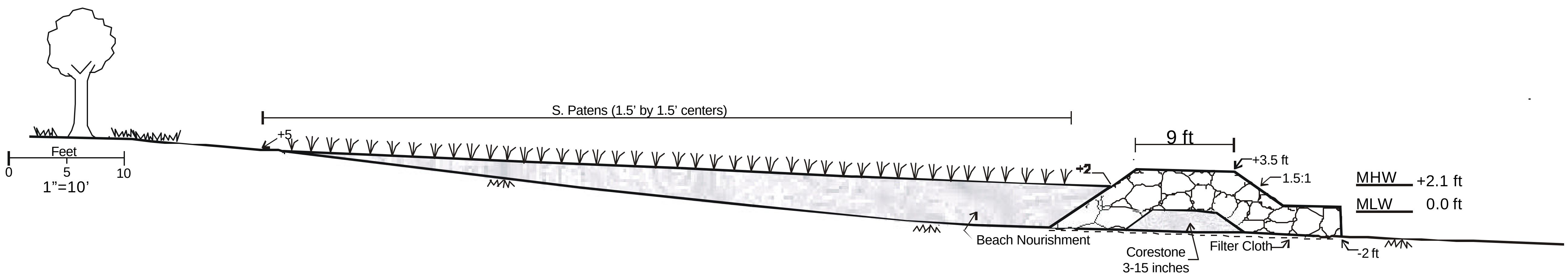


Figure 4-5-3. Recommended low crested (reef) breakwater for Jamestown Island, southwest side, sandy shore.

IV

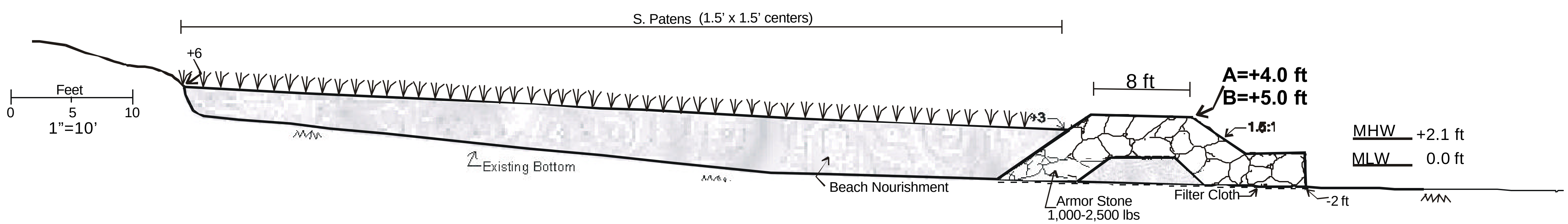


Figure 4-5-4. Recommended breakwater for James River shore fronting the Colonial Parkway.

10 SUMMARY of SHORELINE MANAGEMENT PLAN

10.1 Summary of Plate Results

The process of developing a shoreline management plan begins with the determination of the structures existing along the shoreline as well as the land use associated with the upland area. Table 10-1 summarizes the total shoreline lengths associated with the land use and shoreline attributes discussed in earlier chapters. Also, the client's goals and objectives as well as the physical and hydrodynamic settings of the site need to be taken into consideration when determining what type of structure would be appropriate at the site.

In the Chesapeake Bay estuarine system, shore protection systems can be constructed utilizing breakwaters in combination with spurs, low broad-crested breakwaters, and revetments. These systems are designed to interface with adjacent shorelines thereby minimizing potential downdrift and updrift impacts. These structures are the composite features of the shore protection systems and are critical elements to transition onto adjacent reaches.

Six different structure types were recommended for use along the COLO property in the study area. These include revetments, 2 sills with different crest elevations, low broad-crested breakwaters, and 2 larger breakwaters with different crest elevations. The use of the larger breakwaters for shoreline management is appropriate when: 1) a beach is desired for shore protection, 2) the shore protection project can be interfaced with proposed upland improvements, and 3) when just by hardening strategic points alongshore, the process of developing equilibrium embayments begins.

10.1.1 Plate 1

Shoreline management along much of the James River shorelines (Reaches 304, 306, and 307) already has been addressed with stone revetments and sloping concrete seawalls; however, these structures should be assessed for their structural integrity if they are to continue to provide long-term protection. They currently are providing shoreline erosion control at varying levels. The low revetment, turned sill, along the glasshouse sub-reach protects a very low backshore so that storm waves easily overtop, break and dissipate across the low upland. The potential increase in still water level (sea level) warrants further assessment of the ability of those structures to provide long-term shore protection.

The shorelines along Powhatan Creek, Sandy Bay and Back River are fetch-limited, but tidal currents and potentially boat wakes can exacerbate shoreline erosion. Vertically-exposed eroding upland banks and strategic marsh headlands are the primary targets of the shoreline management plan along Reaches 350, 305A, and 305B. These eroding uplands are interfluves and considered significant in the presence of threatened infrastructure and/or cultural resources. Stone revetments would certainly halt the erosion of these features, but offshore sills with a sand substrate would allow the development of a marsh fringe which is preferred in terms of aesthetics and estuarine habitat.

In the design and construction phase of sills and breakwaters, foundation stability needs to be fully assessed. The substrate along Back River is relatively soft and is a consideration when placing stones along the nearshore since settling can occur.

10.1.2 Plate 2

The upstream third of James River shoreline in Plate 2 on Reach 303 has been protected by defensive measures. These include a sloped concrete seawall at the original Jamestown Fort area (APVA) and for about 2,000 ft downstream of that is a stone revetment. These structures are old and need to be assessed for repair/replacement. The stone revetment at New Towne is being evaluated by the Corps, and preliminary plans suggest adding armor stone and raising the crest elevation of the structure.

The remaining shoreline along Reach 303 is unprotected and eroding but becomes more stable with a widened beach toward Lower Point.

Table 10-1. Summary of shoreline lengths in feet of land use and attributes by year.

Attribute	Shoreline Length (ft) 1974	1993	1997	Land Use	Shoreline Length (ft) 1974	1993/1997
Hardened Structures- Rip Rap, Bulkhead	14,326	14,612	15,047	Private-Unmanaged, Wooded	1,055	1,055
Marsh-Stable	8,182	8,177	8,181	Private-Unmanaged, Nonwooded	248	248
Marsh-Unstable	44,781	47,696	47,727	Recreational-State/Federal	8,509	8,509
Upland-Stable, No Structures	6,841	6,822	6,826	Recreational-Private	2,830	1,354
Upland-Unstable, No Structures	21,961	21,836	21,941	Federal-Unmanaged, Wooded	18,224	18,224
Miscellaneous	2,303	2,014	1,588	Federal-Unmanaged, Nonwooded	69,839	71,315
				Miscellaneous	679	679

Many cultural resources are located in the upland areas. The long-term plan includes breakwaters and spurs strategically-placed along the entire shore in order to begin the process of headland control. Extreme care must be taken when implementing this system. If the system is phased, the first structures placed will begin to impact adjacent shores. The stone breakwaters placed along the sandy beach region need to be low because higher breakwaters will restrict and control the movement of sand alongshore. Some movement behind and across the structures is desired. Ultimate stability calls for the shorelines to evolve to equilibrium planforms. This evolution needs to be understood beforehand and monitored through time to insure cultural and natural resources are not impacted.

The system proposed along the beach-fronted ridge and swale system provides for low reef headland breakwater placement in front of each ridge in order to allow the equilibrium embayments to form in the swales or marsh areas. As a long-term strategy, COLO should consider placing any sand available from dredging offshore navigation channels along shore between established headlands.

10.1.3 Plate 3

Reach 302 in Plate 3 has few cultural resources except Black Point. Black Point is the leading headland feature on the eastern end of Jamestown Island. Managing this features is important to the headland control strategies proposed along both the Thorofare and shores to the southwest along Reach 302. The project at Black Point is in the design phase and will include a low sill with wetland plantings and an opening at the apex of Black Point for water access to a panoramic view of the James River. Beginning the process of headland control along the other sections of Reach 302 should be weighed against more pressing needs along other shore reaches. The portrayed long-term equilibrium embayments will take a long time (possibly 100+ years) to develops since evolution of thick marsh peat shorelines occurs about half as fast as adjacent, low, upland banks.

10.1.4 Plate 4

Management strategies for Plate 4 shorelines (Reaches 298, 299, 300, and 301) include a combination of sills, spurs, and breakwaters that are designed to protect archaeologic sites on Jamestown Island and enhance existing headland features along the Colonial Parkway shoreline. These reaches are in a low to moderate energy wave climate. There are numerous small, subtle pocket beaches whose orientations indicate the dominant direction of wave approach. The proposed strategies are aimed at enhancing existing headlands.

10.1.5 Plate 5

The shore reaches within Plate 5 include Reaches 293, 295, 296, and 297. The water's edge comes relatively close to the Colonial Parkway which has several overlooks in this region. The erosion of the fill material, used to build the Parkway originally, has provided the necessary sand for a moderate to narrow beach. Intermittent to severe bank erosion has allowed subtle geomorphic features to develop as headlands. Creeks, upland drainages, and occasional existing revetments are the headland features to address initially. The proposed strategies require ongoing monitoring to assess development of embayments between structures. To provide a protective edge, additional beach nourishment should be considered along the entirety of Reaches 296 and 297. This material might come from channel dredging.

Reach 293 extends to the COLO's boundary with Kingsmill where a revetment marks the line. This area is essentially an island. The shoreline on the College Creek side of Reach 295 is mostly stable marsh and requires no attention. However, if shoreline strategies are employed along Reaches 296 and 297, the current stable nature of reach 295 on the James River may be compromised. A large sand fill would help alleviate that potential. Therefore, shore monitoring is needed to assess impacts. Additional structures may be required alongshore to protect infrastructure. No equilibrium planforms are shown along the Plate 5 shoreline because beach fill and/or structures will be required on an as-needed basis.

10.2 Cost of Recommended Structures

The summary of the structural elements of the Shoreline Management Plan are shown in Table 10-2 with the unit cost and totals shown in Table 10-3. A $4.5 million dollar price along 14.6 miles of shoreline is about $4/linear foot of shore. However, headland control as a management strategy allows most of the shore to continue to erode as part of the plan. Making prudent adjustments as funding permits will be a challenging, long-term goal.

Table 10-2. Summary of structural elements in the COLO Shoreline Management Plan.

COLO Shoreline Management Plan Structures		Stone (Tons/ft)	Sand (cy/ft)	Plants (no./ft)
Type	Structure			
IA	Sill	2.3	3.3	14
IB	Sill	2.8	3.3	14
II	Breakwater Marsh Shore	5.0	1.1	5
III	Breakwater, Low Crested Jamestown Island	6.2	4.5	17
IVA	Breakwater Colonial Parkway	6.3	14	17
IVB	Breakwater Colonial Parkway	7.9	14	17

10.3 Monitoring

Ongoing monitoring needs to be part of the long range plan. After the phasing options are agreed upon, a reasonable cost/effective monitoring plan will be developed. Aerial photography supporting a shore change database will be the primary tool to monitor shoreline change. In addition, selected sites should be monitored through beach profiling efforts to document cross-sectional changes in the upland bank and beach profile as well as possible changes in structures elevation.

Table 10-3. Summary of structures by Plate number and total cost of all structures.

Location	Structure Type	Parameters: Length (ft)	Parameters: Stone (Tons/ft)	Parameters: Sand (cy/ft)	Parameters: Plants (no./ft)	Total: Stone (Tons)	Total: Sand (cy)	Total: Plants
Plate 1	*IA*	1,800	2.3	3.3	14	4,140	5,940	25,200
	IB	2,500	2.8	3.3	14	7,000	8,250	35,000
					Total	**11,140**	**14,190**	**60,200**
Plate 2	*IVA*	340	6.3	14	17	2,142	4,760	5,780
	IVB	280	7.9	14	17	2,212	3,920	4,760
	III	950	6.2	14	17	5,890	13,300	16,150
					Total	**10,244**	**21,980**	**26,690**
Plate 3	*IB*	250	2.8	3.3	14	700	825	3,500
	II	1,280	5.0	1.1	5	6,400	1,408	6,400
					Total	**7,100**	**2,233**	**9,900**
Plate 4	*IA*	650	2.3	3.3	14	1,495	2,145	9,100
	IB	1,850	2.8	3.3	14	5,180	6,105	25,900
	IVA	800	6.3	14	17	5,040	11,200	13,600
	IVB	690	7.9	14	17	5,451	9,660	11,730
					Total	**17,166**	**29,110**	**60,330**
Plate 5*	*IVA*	500	6.3	14	17	3,150	7,000	8,500
	IVB	1,100	7.9	14	17	8,690	15,400	18,700
					Total	**11,840**	**22,400**	**27,200**
					Grand Total	*57,490*	*89,913*	*159,120*
					Cost per Unit	$45	$18	$1
					INDIVIDUAL COMPONENT COST	**$2,587,050**	**$1,618,434**	**$159,120**
TOTAL PROJECT COST						**$4,364,604**		

*The cost for 80,000 cy of additional beach nourishment sand to enhance stable embayments could range from $5/cy for dredge spoil placement to $15/cy for sand from upland sources. This would increase the total cost estimate by $400,000 to $1,200,000.

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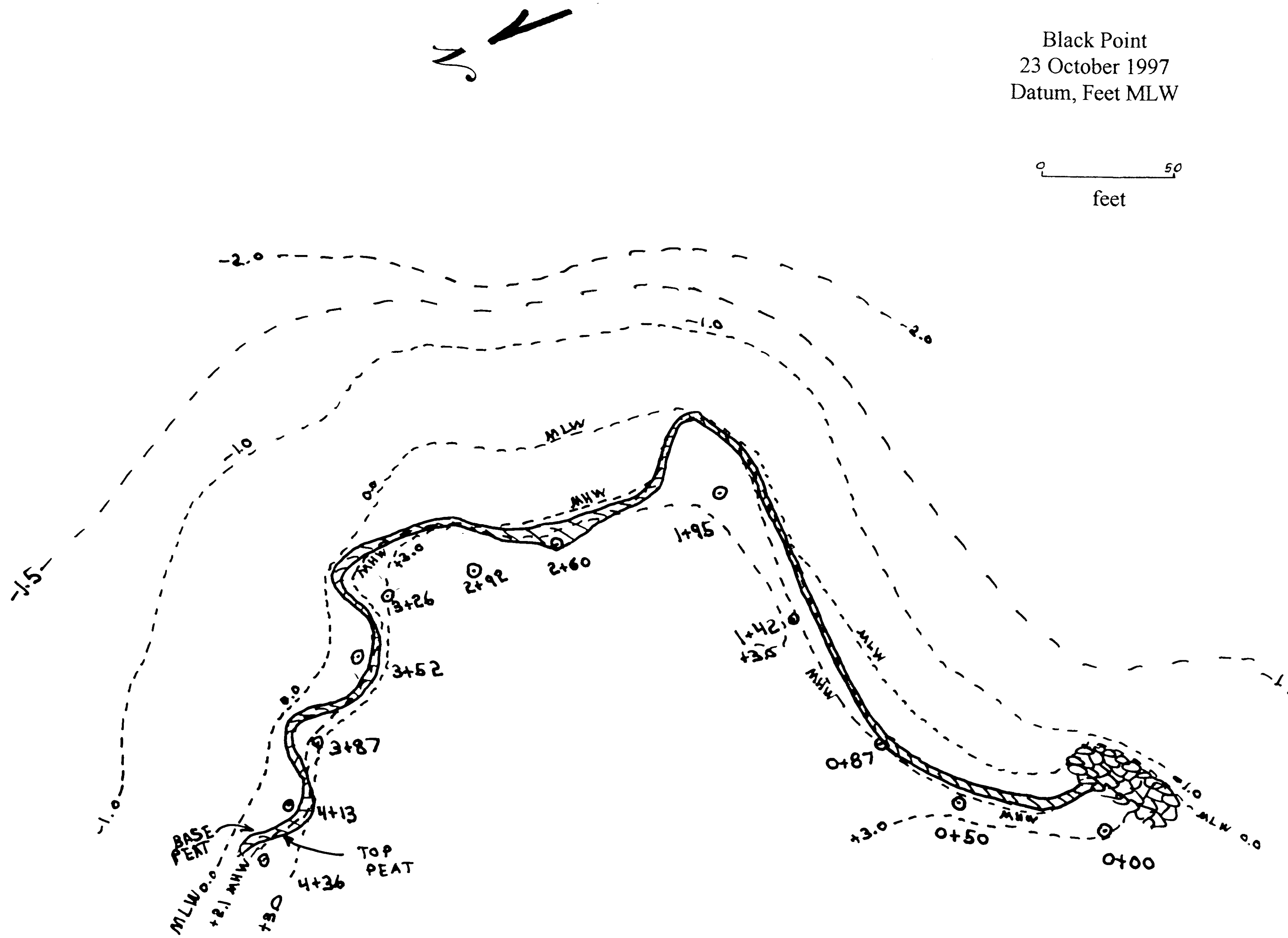
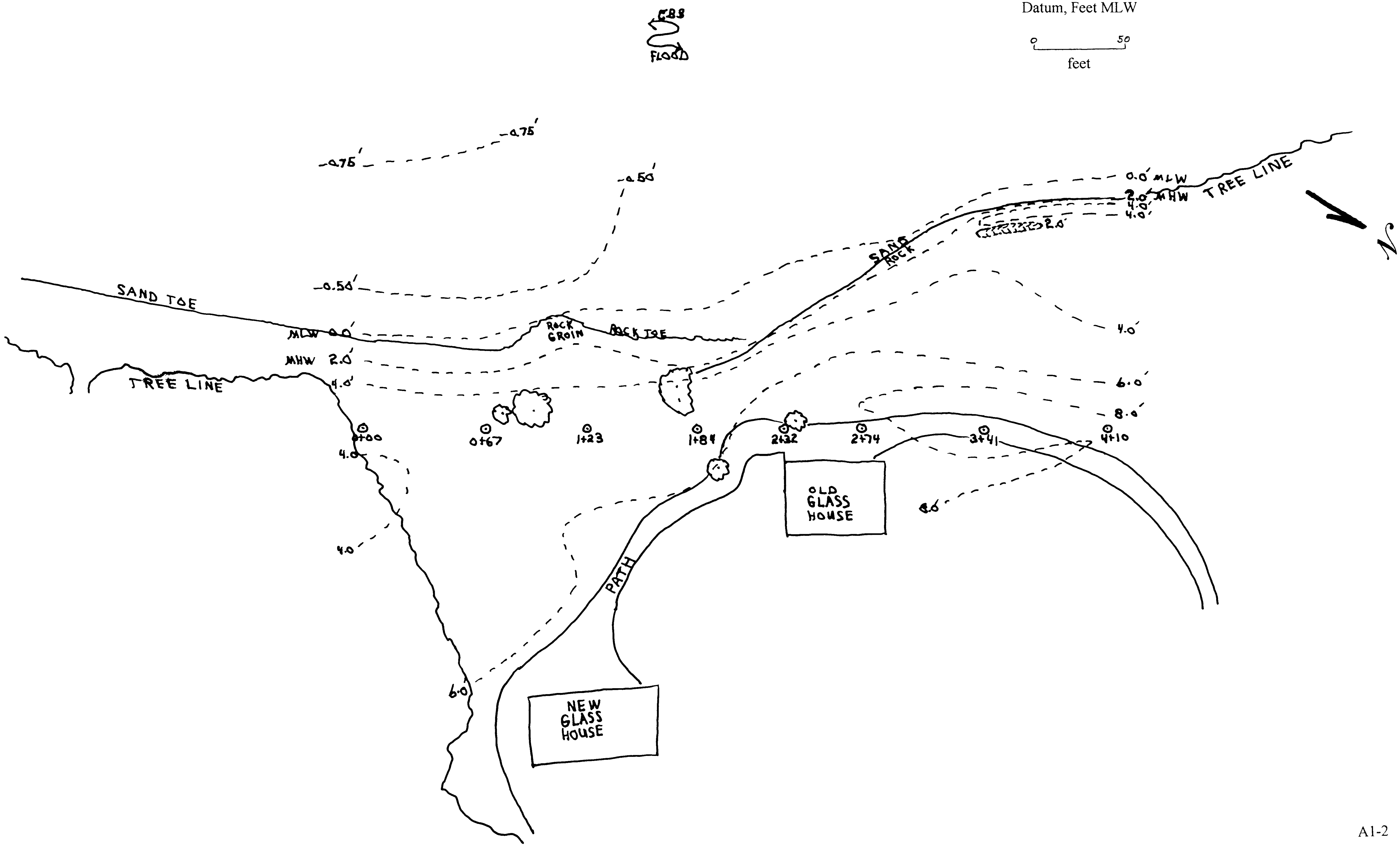
Black Point
23 October 1997
Datum, Feet MLW



Glasshouse Point
24 November 1997
Datum, Feet MLW



Introduction

In order to develop a plan for effective management of the James River shoreline of the Colonial National Historical Park, it is necessary to have a thorough understanding of the region's geology. This report will describe the geology and geological history of Jamestown Island and adjacent areas as reported in the literature. The intent is to present a physical and geographic framework which can be used in the projection of possible future modifications of the Park's shore area, and, as such, which could be of use to park managers and planners.

The James River shoreline of the Colonial National Historical Park is in the Surry and Hog Island 7.5 minute (topographic) quadrangles in James City County, Virginia (Figure A2-1). The region is in the larger Coastal Plain geological province. Since the Hog Island Quadrangle was mapped (Bick and Coch, 1969), there have been some changes in the regional stratigraphic nomenclature; hence this report will attempt to bring the older discussions into conformity with the present usage and understanding. This work will benefit from published reports on nearby areas (Johnson and Berquist, 1989) and numerous other regional surveys and studies, especially the various guidebooks and other documents available from G. H. Johnson of the Department of Geology, College of William & Mary.

Regional Setting

Jamestown Island is within the Coastal Plain geological province. This is the region east of the Fall Zone which is characterized by generally flat lying strata, often of marine origin, occasionally cut by younger, fluvial channels. Although the stratigraphy of Virginia's coastal plain has been a subject of study for generations, *e.g.*, Clark and Miller (1906), the increase in knowledge through time has lead to reevaluation and modification of earlier interpretations. Oaks (1964) and subsequent works (Oaks and Coch, 1973; Oaks and others, 1974) provided a relatively complete stratigraphic sequence that has served as a working framework for following geologists. As additional information has become available, details of the interpretations and consequent nomenclature have been modified. Table A2-1, from Hobbs (1997) after Johnson and Berquist (1989), lists the presently-used terminology. Ramsey (1992) has a discussion of the late Pliocene stratigraphy of the area.

According to various authors (Ramsey, 1988, 1992; Johnson and Berquist, 1989), the Bacons Castle Formation, where present, rests unconformably atop the Yorktown Formation. With an age of 2.3 to 2.0 Ma, the Bacons Castle is considered to be of late Pliocene age. It is generally non-fossiliferous and consists of fluvial to estuarine and tidal-flat deposits. In the past the formation has been called the Columbia Group and the Sedley Formation. Ramsey (1988) proposed that the tidal-flat deposits be termed the Barhamsville member and the fluvial and estuarine deposits be called the Varina Grove member of the Bacons Castle formation. Paleochannels locally cut into older deposits beneath the Bacons Castle. Generally the grain-size of the Bacons Castle grades upwards into finer grained sediments.

Stratigraphically above the Bacons Castle Formation is the Moorings unit. According to Johnson and Berquist (1989), Oaks and Coch (1973) proposed the Moorings unit as an informal stratigraphic unit describing sand and silty clays west of the Surry Scarp. Earlier Wentworth (1930) called it the Sunderland and Coch (1965) called it the Elberon. Coch (1968) and Oaks and Coch (1973) provided further definition. In the Norge quadrangle, just northwest of Jamestown (Hog Island Quadrangle), the Moorings unit has two facies, one sand, the other clay. The unit was deposited in a barrier beach and lagoon environment. Generally each facies is less than 3 m (10 ft) thick. On the basis of its stratigraphic position above the Late Pliocene Bacons Castle and below the Early Pleistocene Windsor, Johnson and Berquist 91989) consider the Moorings to be indeterminately Late Pliocene or Early Pleistocene.

According to Johnson and Berquist (1989), Coch (1968) named the Windsor Formation for a sand, silt, and clay sequence considered to be lagoonal-estuarine in origin. In earlier work, Coch (1965) assigned the strata to the silty sand facies of the Elberon. Earlier workers (Clark and Miller, 1906, 1912; Wentworth, 1930) mapped the unit as the Wicomico formation or the Kilby formation (Moore, 1956). Johnson and Berquist (1989) use a more restrictive definition of the Windsor than had previous authors, hence their maps may not align with those of previous publications. Although lacking definitive fossils, the Windsor is considered Early Pleistocene in age as it is separated from the underlying Late Pliocene Bacons Castle formation by an unconformity and from overlying, hence younger, Middle or Late Pleistocene strata by a disconformity. Johnson and Berquist (1989) state that along the James River the Windsor formation consists of muddy, coarse sand and gravel which grade upward into sandy mud.

The Charles City Formation (Johnson and Berquist, 1989) is "an upward-fining sequence of gravelly sand and silty to clayed sand." Wentworth (1930) used the term Wicomico Formation. The Charles City Formation has been eroded and remains only in some areas, although it can be up to 30 feet thick. The formation lacks fossils, thus its absolute age is unknown. However it is assumed to be Early Pleistocene as it is stratigraphically beneath the Middle Pleistocene Chuckatuck and Shirley Formations.

Chuckatuck Formation has variously been mapped as the Wicomico Formation (Wentworth, 1930) and Windsor Formation (Coch, 1968, Oaks and Coch, 1973) as well as the Chuckatuck (Johnson and Peebles, 1986, 1987) according to Johnson and Berquist (1989). As with most of the other formations of the coastal plain, it consists of a sedimentary sequence that grades upward from coarse to fines materials starting with a cobbly to pebbly sand, progressing through medium and fine sands, and ending with clayey sand or silt. The lowermost beds of the Chuckatuck fill channels that are cut 25 or more feet into the underlying strata.

The Shirley Formation was named by Johnson and Berquist (1989) as an upward fining sequence of a basal, gravelly sand that grades upward to a fine to coarse sand that is overlain by clayey silt or clayey, silty fine-sand. There are interbedded masses of clay and peat. The formation ranges from less than one foot to more than 55 feet in thickness. According to Johnson and Berquist (1989), the Shirley Formation initially was deposited under fluvial conditions in channels cut into older formations. Whereas the upper portion was deposited in the estuaries formed as (relative) sea level rose. Johnson and Berquist place the ace of the Shirley as Late Middle Pleistocene on the basis of Uranium-series dates of 184,000 years (Mixon and others, 1984) and 187,000 years (Cronin and others, 1981).

The Tabb Formation, according to Johnson and Berquist (1989) was named by Johnson (1976) who further identified three members with the overall formation, the Sedgefield, Lynnhaven, and Poquoson. Although across its geographic setting the members exhibit the full range of shallow marine, estuarine, and fluvial facies, only the fluvial estuarine facies exist in the inland-most areas just upstream from the Jamestown area. Wentworth (1930) mapped the Tabb as the Talbot Formation and Bick and Coch (1969), Coch (1971), and Johnson (1972) mapped it as the Norfolk. Each of the members of the formation exhibits the general fining upward sequence common in coastal plain strata. The formation occurs at generally low elevations, the lowermost and youngest member, the Poquoson, crops out on the Mulberry Island Flat. Berquist and Johnson (1989) show the Tabb to be of late Pleistocene age, having been deposited in the period roughly 75,000 to 120,000 years b.p. The Tabb is overlain by Holocene (modern) deposits.

In sum, the regional stratigraphy is a seemingly repetitive series of shallow marine, lagoonal, estuarine, fluvial strata each deposited during a marine transgression. The younger deposits likely being reworked from the older. Figure A2-2 is a portion of the geologic map of Virginia's coastal plain (Mixon and others, 1989).

The exposed sediments in the immediate area of Jamestown Island are Holocene marsh sediments over the Poquoson and Sedgefield Members of the Tabb Formation, and the slightly older Shirley Formation. Much older sediments of the Pliocene age Yorktown Formation crop out in the bluffs just downstream.

Local Situation

Figure A2-3 is a geological cross-section of Jamestown Island. Modern (Holocene) beach and dune sediments, which likely are reworked from the slightly older (Late Pleistocene) Tabb formation, are exposed at the interface with the open water and modern marsh sediments are

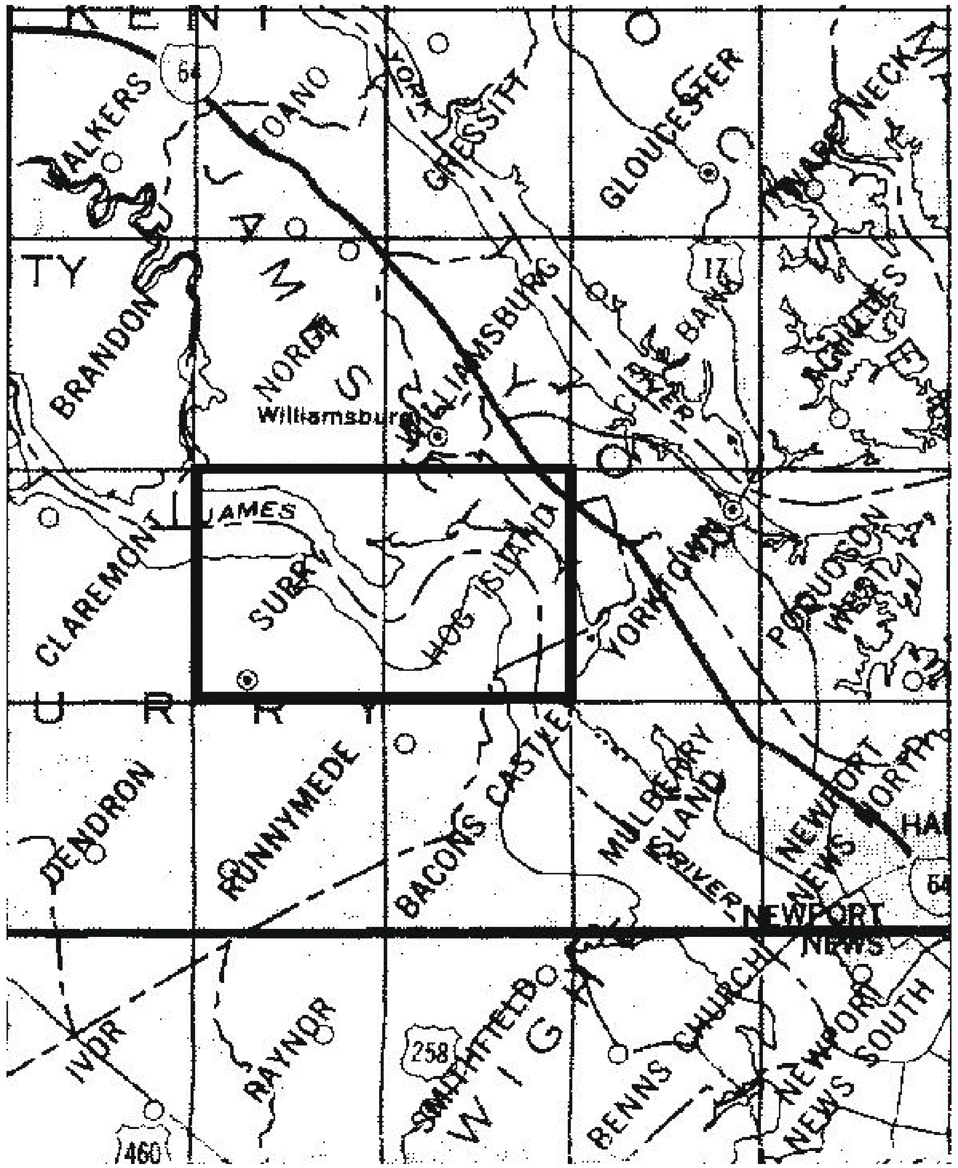


Figure A2-1. Location map indicating the 7-1/2 minute topographic and geological quadrangles in the vicinity of Jamestown Island. Jamestown Island is on the north shore of the James River in the Surry and Hog Island Quadrangles. (Enlarged and adapted from the U.S. Geological Survey's Virginia Index to Topographic and Other Map Coverage.)

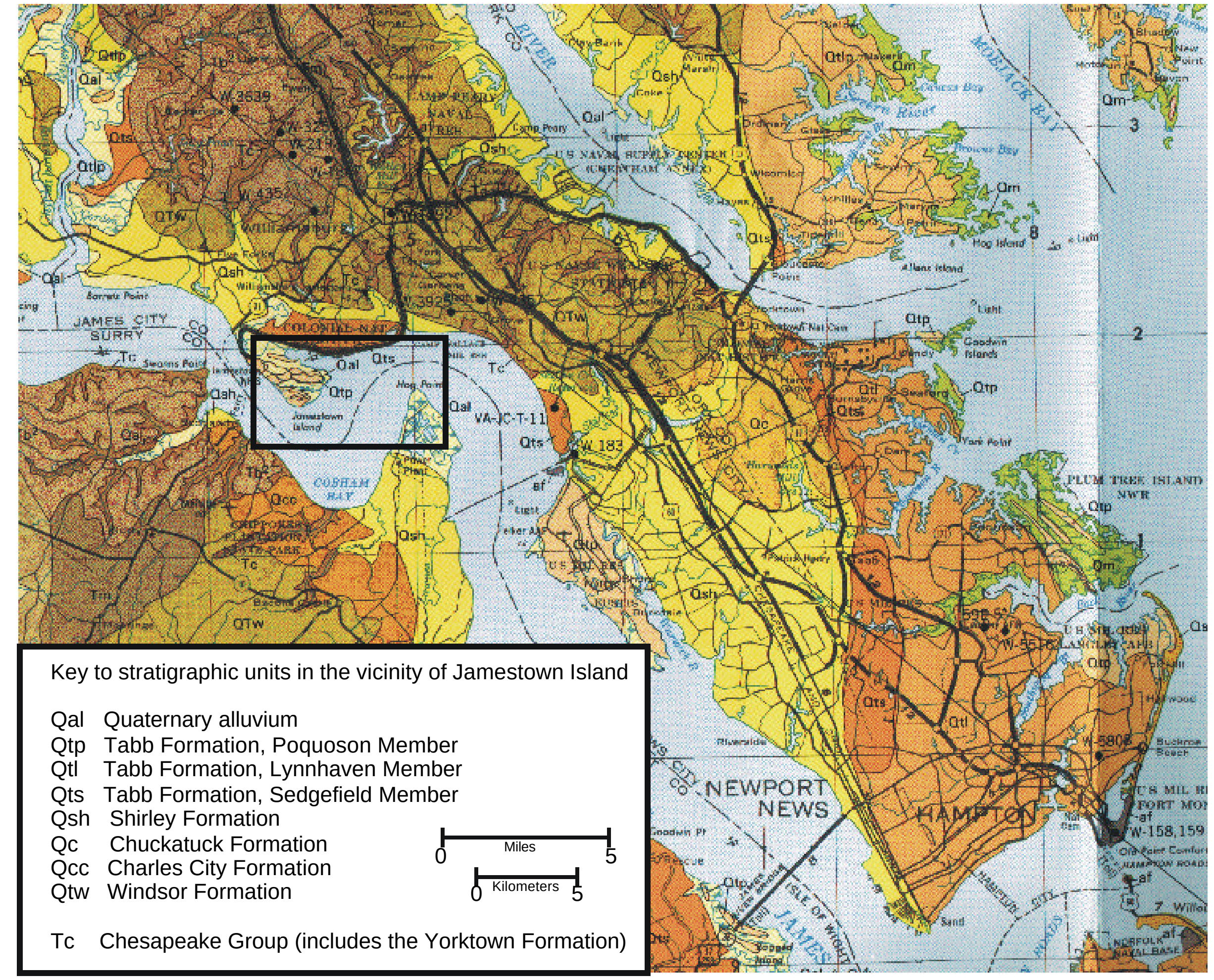


Figure A2-2. Geologic map of the region including Jamestown Island from Mixon *et al*. (1987).

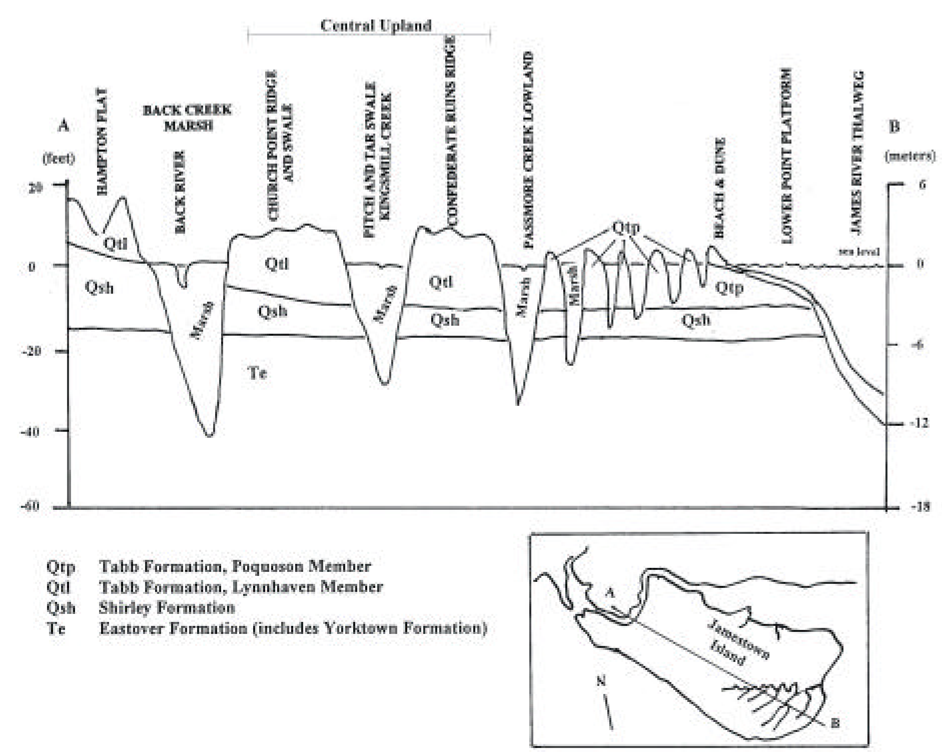


Figure A2-3. Geological cross section of Jamestown Island. Modified from Hobbs *et al*. (1996).

A2-2

exposed along the more restricted waters. If the cross section were extended farther inland, the Shirley Formation would reach the land surface and unconformably pinch-out against the older Windsor Formation.

The relative rates of erosion of sediments along the shoreline is a function of two unrelated factors. The site-specific character of the sediments is critical as is the local "energy" of the water body. As the strata consist of un- or poorly-consolidated sediments, the differences in energy required to resuspend, hence erode, individual types of sediment determine the variations in erosion between equally exposed sections. It takes relatively more energy, interms of waves and currents, to resuspend silts, clays and coarse sands, and coarser sediments than medium- and fine-grained sands. Thus, given equal exposure to waves and currents, the "energy" of the James River, areas of clean, fine and medium sands will eroded more rapidly than other areas. Clays or silts, as in older lagoonal, estuarine, or marsh deposits, exposed to the same energy regime would be more resistant to erosion.

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Table A2-1. Comparison of Nomenclature for the Stratigraphy of Virginia's Coastal Plain.

Oaks and Coch (1973) Oaks and others (1974)		Johnson and Berquist (1989) (inc. Johnson and others (1985))		
HOLOCENE	Unnamed Holocene & Dismal Swamp peat	Unnamed Holocene deposits		HOLOCENE
PLEISTOCENE	Sandbridge Fm.	Tabb Fm	Poquoson Mbr	PLEISTOCENE
	Londonbridge Fm.		Lynnhaven Mbr	
	Kempsville Fm. Norfolk Fm.		Sedgefield Mbr	
		Shirley Fm.		
	Great Bridge Fm.			
		Chuckatuck Fm.		
	Windsor Fm.	Charles City Fm.		
		Windsor Fm. (restricted)		
PLEISTOCENE AND/OR PLIOCENE	"Moorings" unit	"Moorings" unit		PLIOCENE
	Bacons Castle Fm.	Bacons Castle Fm.		
		Chowan River Fm.		
MIOCENE	Sedley Fm.	Yorktown Fm		
	Yorktown Fm.	Eastover Fm.		MIOCENE

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Wind-Generated Waves

The wave climate acting upon COLO's shoreline is created by winds blowing up, down, and across the James River. The study area is affected by northeast and northwest winds which occur during the late fall to early spring as well as southwest and westerly winds that are most frequent during the early spring to late fall (Rosen, 1978). In order to determine the wave energy impacting the shoreline, the wave parameters were determined with the SMB model. These wave parameters were used as input to RCPWAVE. RCPWAVE output wave parameters were used to determine the longshore transport for a specific reach of shoreline and as input to the Static Equilibrium Bay (SEB) empirical model.

Six grids (Figure A3-1) were digitized from bathymetric charts to model the wave climate along COLO's shoreline on the James River. Grids #5 and #6 are in the same location along the southwestern side of Jamestown Island as Grids #1 and #2, but the orientation is different so that the northwest wave conditions could be modeled. Grid #3 models the southeastern side of the Island while Grid #4 models the James River's shore fronting the Colonial Parkway. The Thorofare, Sandy Bay, Back River, and Powhatan Creek shorelines were not modeled since they are very fetch-limited.

In order to develop a wave climate evaluation, it is necessary to provide RCPWAVE with reasonable incident wave conditions. The wave prediction model initially developed by Sverdrup and Munk (1947) and revised by Bretschneider (1952, 1958) was modified by Kiley (1982). SMB is a shallow water estuarine wind-generated wave prediction model. The wave prediction procedure, utilized in previous projects (Hardaway *et al*., 1991; Hardaway *et al*., 1993; Milligan *et al.*, 1996), was used to produce a set of wave conditions for input into RCPWAVE. The procedure involves the following steps for each grid:

- Determine effective fetch for each grid using procedures outlined in the U.S. Army Corps of Engineers Shore Protection Manual (1984).
- Use the above data as input into the SMB program which provides wave height and period for a suite of wind speeds and water levels.

For Grid #1, effective fetches were determined for the south and southwest directions. For Grid #2, the effective fetch directions were west, southwest, and south. For Grids #3 and #4, effective fetches were determined for the east, southeast, and south directions. For Grid #5, the effective fetches for both the northwest and west directions were calculated. For Grid #6, only the northwest fetch was determined. The SMB analysis was designed to determine wave conditions at the center of the offshore boundary of each grid (Figure A3-1). The local wave climate input for RCPWAVE is represented by wind/wave hindcasting by using wind data from Norfolk International Airport (Table A3-1). Wind data from the Surry Power Plant was obtained for this study since it is closer to the site. However, its location limited the data's usefulness since they was not indicative of wind conditions over open water.

SMB analysis results for each grid are shown in Table A3-2. The wind speed and associated water level (surge) associated with a specific wind were input to the SMB model and the outputs are as shown. Wind speeds less than 36 mph are considered modal or annual wave conditions. Winds averaging 46 mph are indicative of a 10-year storm event and the storm event may have a 6.5 ft surge level. The higher wind speeds (60, 70, and 80 mph), while not specifically found in the Norfolk wind data, are estimates for a 25-year, 50-year, and 100-year storm event that may impact the study area.

Wave Modeling

RCPWAVE takes an incident wave condition at the seaward boundary of the grid and allows it to propagate shoreward across the nearshore bathymetry. Frictional dissipation due to bottom roughness is accounted for in this analysis and is relative in part to the mean sand size (0.15 mm). Waves also tend to become smaller over shallower bathymetry and remain larger over deeper bathymetry. In general waves break when the ratio of wave height to water depth equals 0.78 (Komar, 1976). Upon entering shallow water, waves are subject to refraction, in which the direction of wave travel changes with decreasing depth of water in such a way that wave crests tend to parallel the depth contours. Irregular bottom topography can cause waves to be refracted in a complex way and produce variations in the wave height and energy along the coast (Komar, 1976).

Figures A3-2, A3-3, and A3-4 show wave vector plots for all the grids. Representative wave vector plots are shown for a dominant modal condition (26 mph) and a 25-year storm event (60 mph). The bold line indicates the approximate position of MLW. Increased water levels change the position of the bathymetric contours, shifting the zero, or the vertical datum's limit, inland. When water levels are increased significantly, the wave vector plots show waves impacting inland. The limit of impact on the upland will be determined by the true elevation of the upland which was not modeled in this analysis.

Table A3-1. Summary wind conditions at Norfolk International Airport from 1960-1990.

		WIND DIRECTION								
Wind Speed (mph)	**Mid Range (mph)**	**South**	**South west**	**West**	**North west**	**North**	**North east**	**East**	**South east**	**Total**
< 5	3	5497* 2.12+	3316 1.28	2156 0.83	1221 0.47	35748 13.78	2050 0.79	3611 1.39	2995 1.15	56594 21.81
5-11	8	21083 8.13	15229 5.87	9260 3.57	6432 2.48	11019 4.25	13139 5.06	9957 3.84	9195 3.54	95314 36.74
11-21	16	14790 5.70	17834 6.87	10966 4.23	8404 3.24	21816 8.41	16736 6.45	5720 2.20	4306 1.66	100572 38.77
21-31	26	594 0.23	994 0.38	896 0.35	751 0.29	1941 0.75	1103 0.43	148 0.06	60 0.02	6487 2.5
31-41	36	25 0.01	73 0.03	46 0.02	25 0.01	162 0.06	101 0.04	10 0.00	8 0.00	450 0.17
41-51	46	0 0.00	0 0.00	0 0.00	1 0.00	4 0.00	4 0.00	1 0.00	0 0.00	10 0.00
Total		41989 16.19	37446 14.43	23324 8.99	16834 6.49	70690 27.25	33133 12.77	19447 7.50	16564 6.38	259427 100.00

*Number of occurrences +Percent

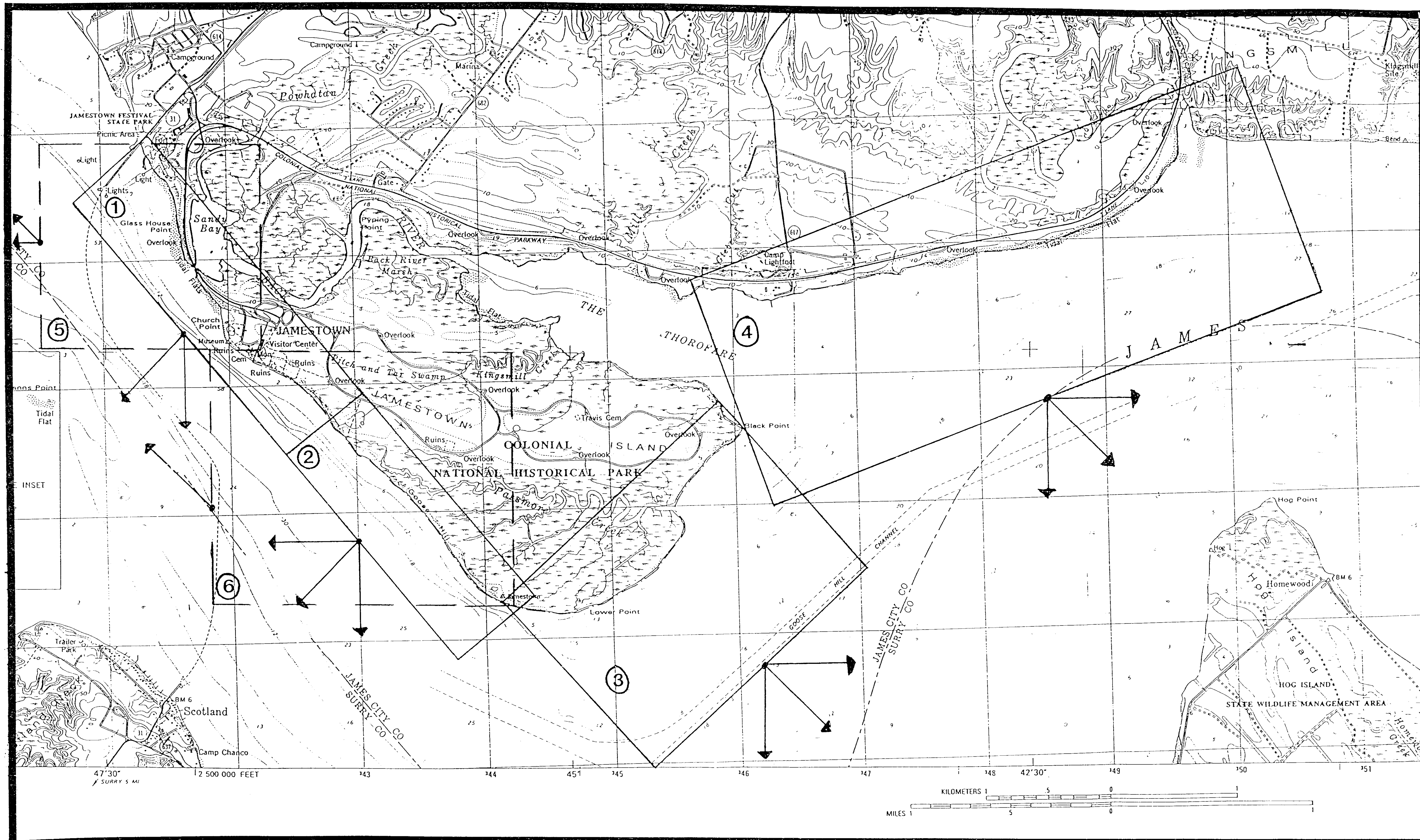

Figure A3-1. Location of RCPWAVE grids and the direction of fetch calculation.

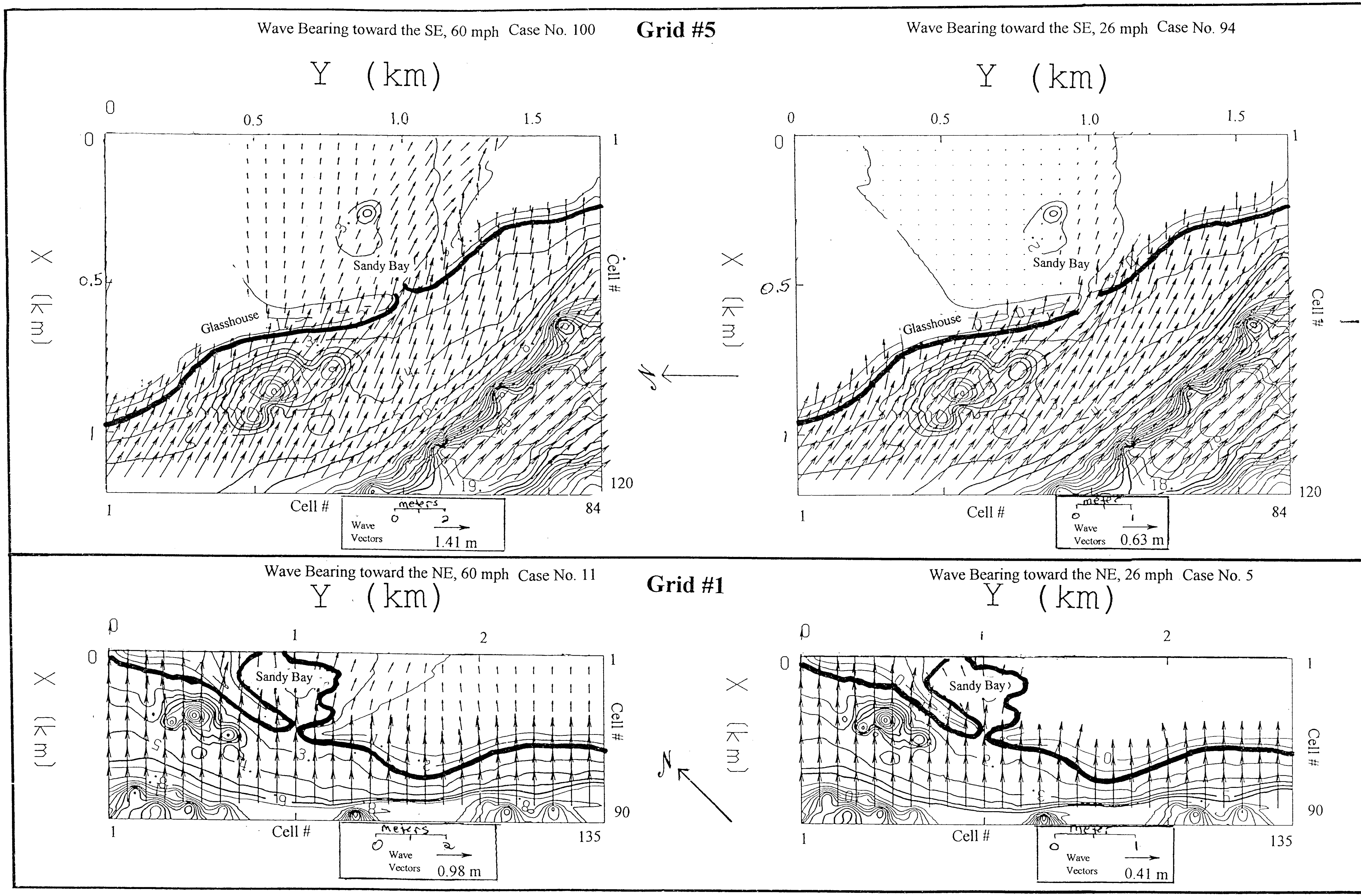

Figure A3-2. Grid #1 and #5 wave vector plots under modal and storm conditions.

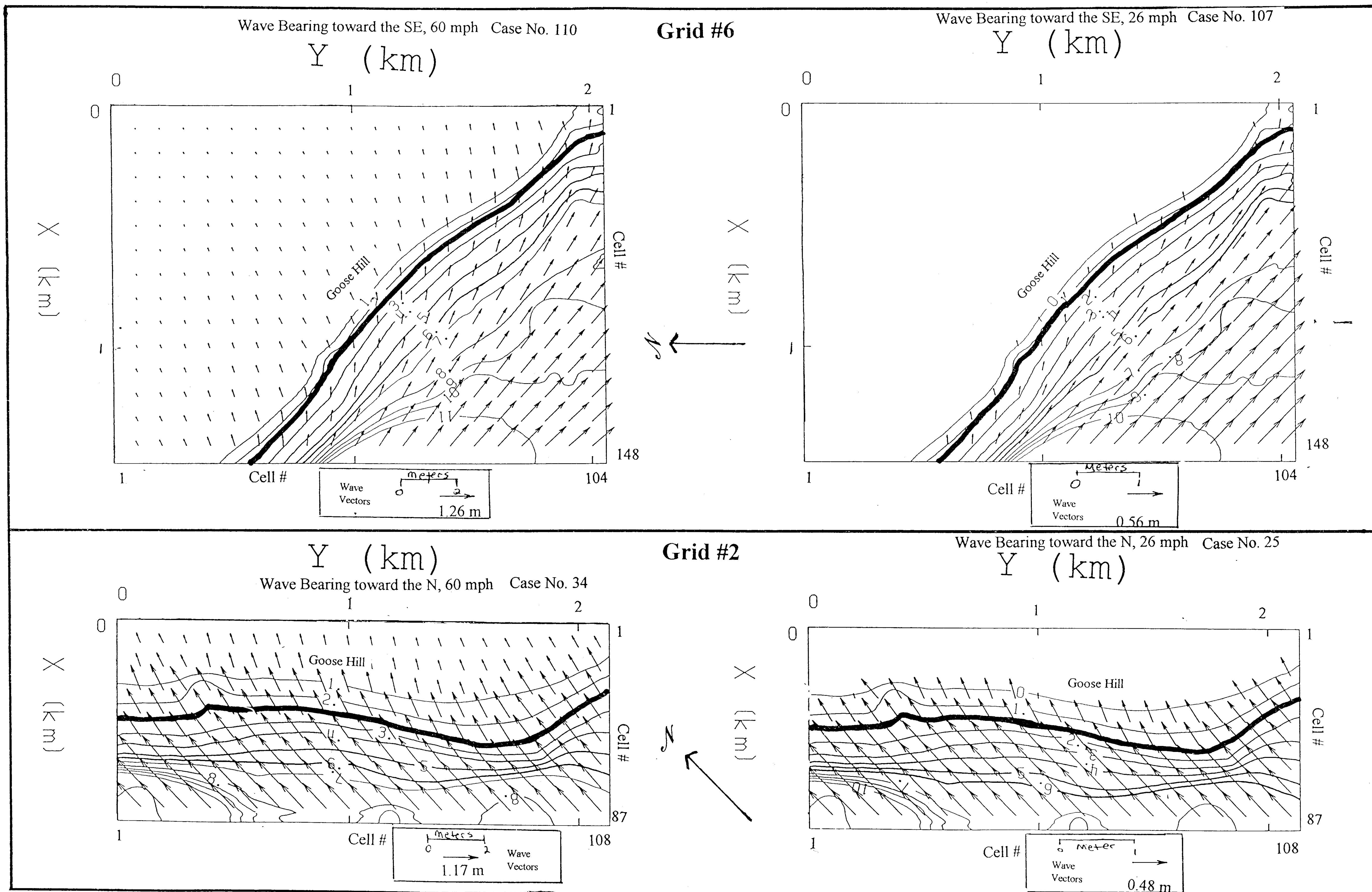

Figure A3-3. Grid #2 and #6 wave vector plots under modal and storm conditions.

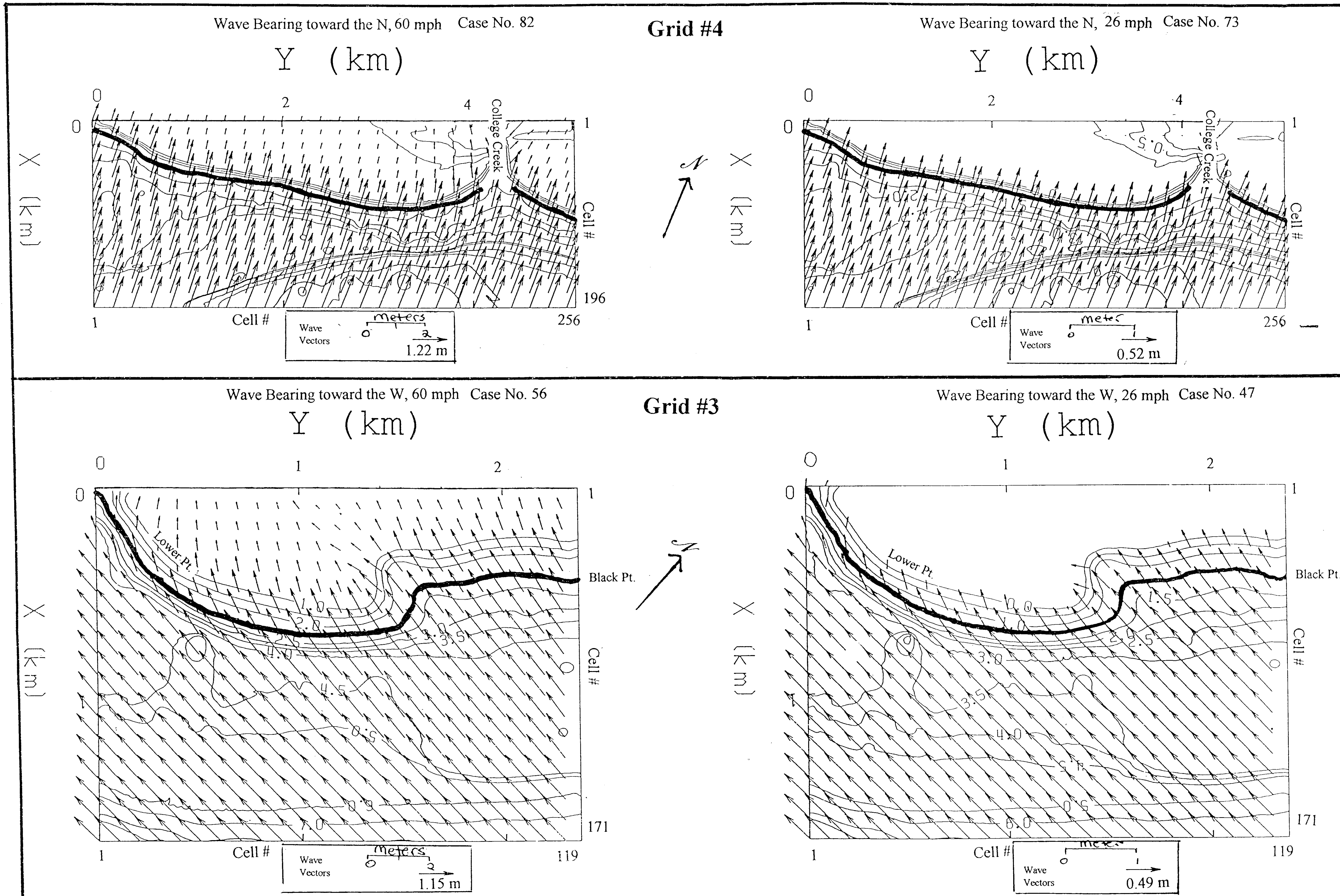

Figure A3-4. Grid #3 and #4 wave vector plots under modal and storm conditions.

Table A3-2. SMB analysis results and the input to RCPWAVE for each grid.

Grid No.	Case No.	Wind Sp. (mph)	Surge (ft)	(m)	Height (ft)	(m)	Period (sec)	Bearing TN)
Grid 1	1	8	2.0	0.6	0.47	0.14	1.45	45
	2	8	2.0	0.6	0.42	0.13	1.41	0
	3	16	3.0	0.9	0.90	0.27	1.93	45
	4	16	3.0	0.9	0.95	0.29	2.04	0
	5	26	4.0	1.2	1.35	0.41	2.31	45
	6	26	4.0	1.2	1.62	0.49	2.59	0
	7	36	5.0	1.5	1.81	0.55	2.62	45
	8	36	5.0	1.5	2.30	0.70	3.02	0
	9	46	6.5	2.0	2.29	0.70	2.89	45
	10	46	6.5	2.0	2.99	0.91	3.37	0
	11	60	7.5	2.3	3.21	0.98	3.34	45
	12	60	7.5	2.3	3.94	1.20	3.80	0
	13	70	8.5	2.6	3.70	1.13	3.55	45
	14	70	8.5	2.6	4.62	1.41	4.07	0
	15	80	9.0	2.7	4.21	1.28	3.75	45
	16	80	9.0	2.7	5.31	1.62	4.32	0
Grid 2	17	8	2.0	0.6	0.42	0.13	1.40	90
	18	8	2.0	0.6	0.49	0.15	1.48	45
	19	8	2.0	0.6	0.40	0.12	1.37	0
	20	16	3.0	0.9	0.93	0.28	2.01	90
	21	16	3.0	0.9	0.95	0.29	1.99	45
	22	16	3.0	0.9	0.90	0.27	1.98	0
	23	26	4.0	1.2	1.59	0.48	2.55	90
	24	26	4.0	1.2	1.45	0.44	2.39	45
	25	26	4.0	1.2	1.56	0.48	2.52	0
	26	36	5.0	1.5	2.26	0.69	2.97	90
	27	36	5.0	1.5	1.95	0.59	2.71	45
	28	36	5.0	1.5	2.23	0.68	2.95	0
	29	46	6.5	2.0	2.92	0.89	3.33	90
	30	46	6.5	2.0	2.46	0.75	3.01	45
	31	46	6.5	2.0	2.91	0.89	3.32	0
	32	60	7.5	2.3	3.84	1.17	3.75	90
	33	60	7.5	2.3	3.48	1.06	3.49	45
	34	60	7.5	2.3	3.85	1.17	3.76	0
	35	70	8.5	2.6	4.50	1.37	4.03	90
	36	70	8.5	2.6	4.00	1.22	3.72	45
	37	70	8.5	2.6	4.53	1.38	4.05	0
	38	80	9.0	2.7	5.16	1.57	4.29	90
	39	80	9.0	2.7	4.53	1.38	3.93	45
	40	80	9.0	2.7	5.21	1.59	4.31	0
Grid 3	41	8	2.0	0.6	0.43	0.13	1.40	270
	42	8	2.0	0.6	0.56	0.17	1.57	315
	43	8	2.0	0.6	0.41	0.12	1.37	0
	44	16	3.0	0.9	0.95	0.29	2.02	270
	45	16	3.0	0.9	1.08	0.33	2.11	315
	46	16	3.0	0.9	0.90	0.27	1.97	0
	47	26	4.0	1.2	1.61	0.49	2.56	270
	48	26	4.0	1.2	1.60	0.49	2.52	315
	49	26	4.0	1.2	1.52	0.46	2.48	0
	50	36	5.0	1.5	2.26	0.69	2.98	270
	51	36	5.0	1.5	2.12	0.65	2.86	315
	52	36	5.0	1.5	2.14	0.65	2.89	0
	53	46	6.5	2.0	2.90	0.88	3.34	270
	54	46	6.5	2.0	2.65	0.81	3.16	315
	55	46	6.5	2.0	2.75	0.84	3.23	0
Grid 3	56	60	7.5	2.3	3.77	1.15	3.77	270
(cont.)	57	60	7.5	2.3	3.63	1.11	3.65	315
	58	60	7.5	2.3	3.58	1.09	3.64	0
	59	70	8.5	2.6	4.39	1.34	4.06	270
	60	70	8.5	2.6	4.15	1.26	3.89	315
	61	70	8.5	2.6	4.18	1.27	3.91	0
	62	80	9.0	2.7	5.02	1.53	4.32	270
	63	80	9.0	2.7	4.68	1.43	4.11	315
	64	80	9.0	2.7	4.79	1.46	4.17	0
Grid 4	65	8	2.0	0.6	0.49	0.15	1.51	270
	66	8	2.0	0.6	0.56	0.17	1.59	315
	67	8	2.0	0.6	0.45	0.14	1.44	0
	68	16	3.0	0.9	1.10	0.34	2.20	270
	69	16	3.0	0.9	1.08	0.33	2.13	315
	70	16	3.0	0.9	0.99	0.30	2.08	0
	71	26	4.0	1.2	1.89	0.58	2.80	270
	72	26	4.0	1.2	1.63	0.50	2.54	315
	73	26	4.0	1.2	1.69	0.52	2.63	0
	74	36	5.0	1.5	2.68	0.82	3.27	270
	75	36	5.0	1.5	2.17	0.66	2.89	315
	76	36	5.0	1.5	2.38	0.73	3.06	0
	77	46	6.5	2.0	3.46	1.05	3.68	270
	78	46	6.5	2.0	2.73	0.83	3.19	315
	79	46	6.5	2.0	3.07	0.94	3.43	0
	80	60	7.5	2.3	4.52	1.38	4.15	270
	81	60	7.5	2.3	3.80	1.16	3.69	315
	82	60	7.5	2.3	4.00	1.22	3.86	0
	83	70	8.5	2.6	5.27	1.61	4.46	270
	84	70	8.5	2.6	4.35	1.33	3.92	315
	85	70	8.5	2.6	4.68	1.43	4.14	0
	86	80	9.0	2.7	6.02	1.83	4.75	270
	87	80	9.0	2.7	4.92	1.50	4.14	315
	88	80	9.0	2.7	5.35	1.63	4.40	0
Grid 5	89	8	2.0	0.6	0.66	0.20	1.72	90
	90	8	2.0	0.6	0.73	0.22	1.84	135
	91	16	3.0	0.9	1.25	0.38	2.29	90
	92	16	3.0	0.9	1.40	0.43	2.46	135
	93	26	4.0	1.2	1.83	0.56	2.71	90
	94	26	4.0	1.2	2.08	0.63	2.93	135
	95	36	5.0	1.5	2.40	0.73	3.06	90
	96	36	5.0	1.5	2.74	0.84	3.30	135
	97	46	6.5	2.0	2.97	0.91	3.37	90
	98	46	6.5	2.0	3.40	1.04	3.62	135
	99	60	7.5	2.3	4.01	1.22	3.85	90
	100	60	7.5	2.3	4.64	1.41	4.13	135
	101	70	8.5	2.6	4.57	1.39	4.09	90
	102	70	8.5	2.6	5.29	1.61	4.36	135
	103	80	9.0	2.7	5.14	1.57	4.31	90
	104	80	9.0	2.7	5.93	1.81	4.59	135
Grid 6	105	8	2.0	0.6	0.65	0.20	1.69	135
	106	16	3.0	0.9	1.24	0.38	2.28	135
	107	26	4.0	1.2	1.84	0.56	2.75	135
	108	36	5.0	1.5	2.44	0.74	3.14	135
	109	46	6.5	2.0	3.03	0.92	3.49	135
	110	60	7.5	2.3	4.15	1.26	4.09	135
	111	70	8.5	2.6	4.73	1.44	4.37	135
	112	80	9.0	2.7	5.31	1.62	4.63	135

Littoral Transport

The movement of sand along a beach zone is dependent on breaking wave height and angle of wave approach. Applications of littoral drift formulae are subject to large errors; hence, the absolute magnitudes predicted must be considered suspect or, at best, accepted with caution (Wright *et al*., 1987). However, the relative magnitudes as they vary along the coast under different wave scenarios is probably more meaningful as are predicted directions of transport. Overall, the $\pm$50% accuracy of littoral drift methods probably provides a first order estimate of littoral drift along straight, low-gradient beaches.

The methods of littoral drift used here are known as the CERC formula (U.S. Army Corps of Engineers, 1984). The rate (Q) at which littoral drift is moved parallel to the shoreline is the longshore transport rate. Since this movement is parallel to the shoreline, there are two possible directions, right or left, relative to an observer standing on the shore looking out over the water. Movement from the observer's right to his left is motion toward the left (Qleft (-)), while movement toward the observer's right is known as Qright (+). Gross longshore transport is the sum of the amounts of littoral drift transported to the right and to the left past a point on the shoreline in a given time period. Net longshore transport is defined as the difference between the amounts of littoral drift transported to the right and to the left past a point on the shoreline in a given time period.

For each wave condition analyzed in RCPWAVE, the breaking wave height and angle were exported and used to calculate the Gross, Net, Qright, and Qleft transport rates. The transport rates were calculated for each grid, but only the rates for Grid #4 are shown in Figure A3-5. The filename (*e.g.* # 72) corresponds with the case number shown on Table A3-2. The count cells number indicates the number of alongshore

Waves heading toward the

26 mph	West	Northwest	North
Summary	# 72	# 73	# 74
Gross (cy/yr)	950	3,199	2,894
Net (cy/yr)	889	2,714	(2,335)
Qleft (cy/yr)	30	243	2,615
Qright (cy/yr)	919	2,956	279
Count Cells-b	66	93	118
Percent	25.8%	36.3%	46.1%

36 mph	West	Northwest	North
Summary	# 75	# 76	# 77
Gross (cy/yr)	21,545	26,049	23,572
Net (cy/yr)	21,512	21,247	(8,680)
Qleft (cy/yr)	16	2,401	16,126
Qright (cy/yr)	21,529	23,648	7,446
Count Cells-b	196	217	235
Percent	76.6%	84.8%	91.8%

46 mph	West	Northwest	North
Summary	# 78	# 79	# 80
Gross (cy/yr)	91,126	87,335	81,140
Net (cy/yr)	90,669	72,738	(61,619)
Qleft (cy/yr)	228	7,299	71,380
Qright (cy/yr)	90,898	80,036	9,760
Count Cells-b	171	209	236
Percent	66.8%	81.6%	92.2%

60 mph	West	Northwest	North
Summary	# 81	# 82	# 83
Gross (cy/yr)	255,240	302,126	233,059
Net (cy/yr)	240,904	267,503	(165,688)
Qleft (cy/yr)	7,168	17,312	199,374
Qright (cy/yr)	248,072	284,815	33,686
Count Cells-b	139	201	228
Percent	54.3%	78.5%	89.1%

70 mph	West	Northwest	North
Summary	# 84	# 85	# 86
Gross (cy/yr)	358,068	573,646	439,161
Net (cy/yr)	349,980	480,043	(328,722)
Qleft (cy/yr)	4,044	46,801	383,942
Qright (cy/yr)	354,024	526,845	55,219
Count Cells-b	91	164	205
Percent	35.5%	64.1%	80.1%

80 mph	West	Northwest	North
Summary	# 87	# 88	# 89
Gross (cy/yr)	798,499	1,039,224	859,657
Net (cy/yr)	797,898	915,718	(440,804)
Qleft (cy/yr)	301	61,753	650,230
Qright (cy/yr)	798,198	977,471	209,427
Count Cells-b	117	179	232
Percent	45.7%	69.9%	90.6%

Figure A3-5. Transport rates calculated for RCPWAVE Grid #4 for the cases show.

cells that had breaking waves. Waves generally do not numerically break because they are either too small or too large to reach the breaking wave criteria. Grid #4 has 135 alongshore cells. Only 32 cells (or about 24%) had breaking waves under the 26 mph northeast wave condition. A similar chart was produced for each grid. The net transport was mean-weighed against the number of occurrences in the Norfolk wind data for each condition. The net result is shown in the main body of the report.

Static Equilibrium Bays

The dominant modal direction of transport and corresponding angle of wave approach in the nearshore are the main parameters in the Static Equilibrium Bay (SEB) model. Figure A3-6 shows the relationship of the tripartite process of SMB, RCPWAVE, and SEB. Figure A3-7 are parameters used to determine the bay shape between headland breakwaters where $\mathbf{R_o}$ is the control line distance, **b** is the angle between the control line and dominant direction of wave approach, **R** is the distance between the diffraction point and the shoreline within the embayment, and **q** is the angle from wave approach to **R**. Table A3-3 shows the relationship of these parameters and corresponding values.

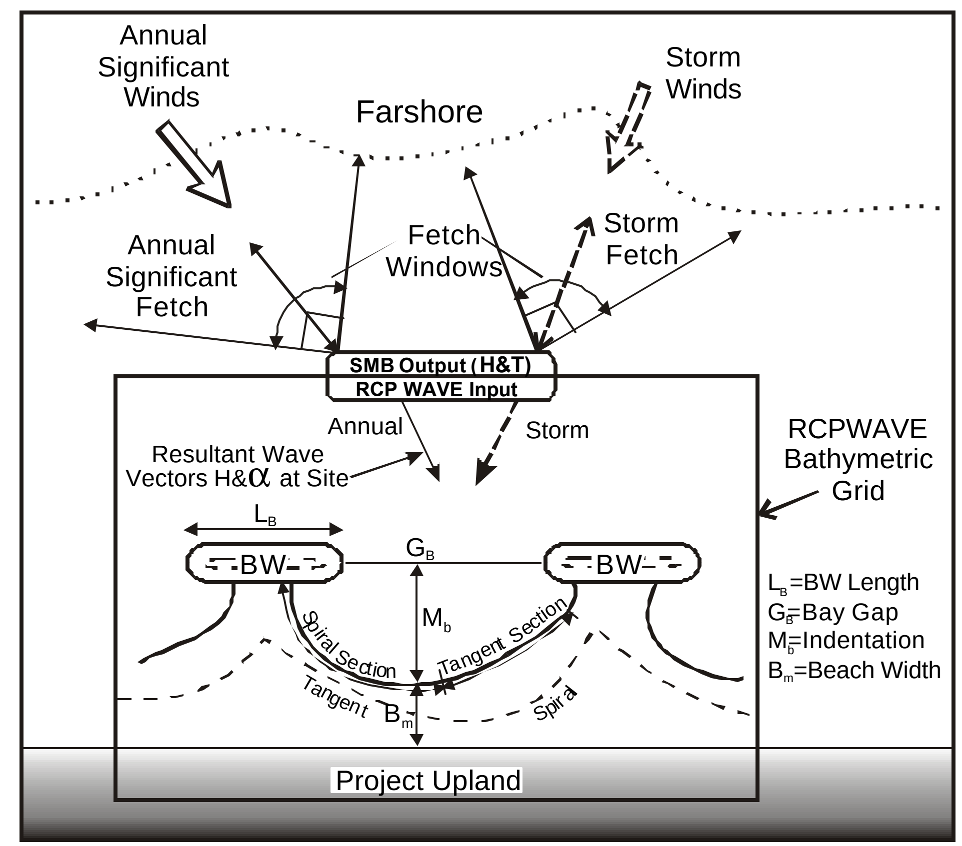

Figure A3-6. Parameters related to wind/wave generation (SMB), nearshore wave refraction (RCPWAVE), and beach planform prediction (SEB).

This system is best used to establish bay shape for sandy beaches between headland breakwaters. Storm waves from opposite directions also can be modeled by setting the landward position of the control line at an elevation comparable to the storm surge elevation. If the dominant direction of storm wave approach is different than the direction of the modal wave approach, the bay shape will change. The advantage of plotting storm bay shapes is that the landward and alongshore extent of the storm event will be shown.

Limited sand transport between adjacent embayments is desirable when impacts to adjacent shorelines are a concern or when the impinging wave climate is a bimodal. Low crested (reef) breakwaters allow for this limited transport, particularly during moderate storm events. Quantifying bimodal sand transport mechanisms is difficult using existing models. Knowing the geomorphic shore evolution and applying littoral transport and bay shape models provides a best estimate of long-term shoreline change. This is true particularly if one is allowing an upland or marsh region to evolve to stable equilibrium. A process of dynamic equilibrium must be gone through before static equilibrium is reached.

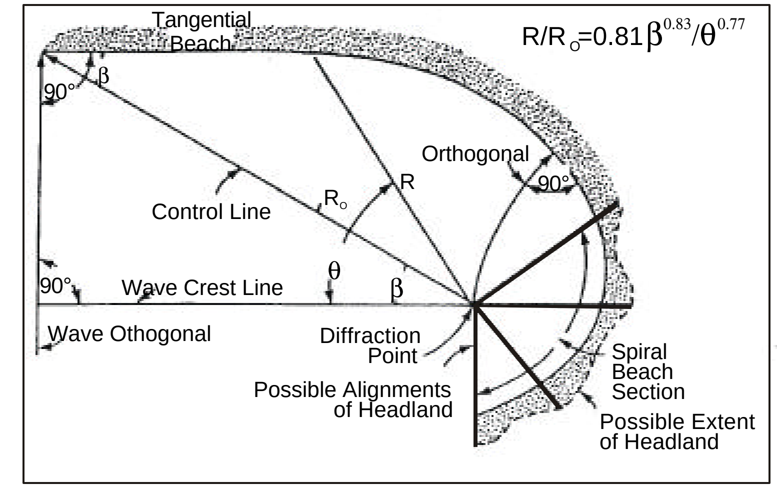

Figure A3-7. Parameters of the Static Equilibrium Bay (after Hsu et al., 1989).

Table A3-3. Means for determining radii rations (R/R_o) (from Silvester and Hsu, 1993).

	Values of R/R_o for q =							
b	30	45	60	75	90	120	150	180
20	0.705	0.497	0.390	0.324	0.280	0.225	0.191	0.168
22	0.768	0.543	0.426	0.354	0.305	0.244	0.206	0.181
24	0.829	0.588	0.461	0.383	0.330	0.263	0.222	0.194
26	0.887	0.633	0.497	0.412	0.355	0.281	0.237	0.207
28	0.944	0.677	0.532	0.442	0.379	0.300	0.251	0.219
30	1.000	0.721	0.568	0.471	0.404	0.319	0.266	0.230
32		0.763	0.603	0.500	0.429	0.337	0.280	0.242
34		0.805	0.638	0.529	0.453	0.355	0.294	0.252
36		0.845	0.672	0.558	0.478	0.373	0.307	0.262
38		0.883	0.706	0.586	0.502	0.390	0.320	0.272
40		0.919	0.739	0.615	0.526	0.407	0.332	0.281
42		0.953	0.771	0.643	0.550	0.424	0.344	0.289
44		0.983	0.802	0.670	0.573	0.441	0.356	0.297
46			0.832	0.698	0.596	0.457	0.367	0.304
48			0.861	0.724	0.619	0.473	0.378	0.311
50			0.888	0.750	0.642	0.489	0.388	0.317
52			0.914	0.775	0.664	0.505	0.398	0.322
54			0.938	0.800	0.686	0.520	0.408	0.327
56			0.960	0.823	0.707	0.535	0.417	0.332
58			0.981	0.846	0.728	0.549	0.425	0.336
60			1.000	0.867	0.748	0.563	0.434	0.339
62				0.888	0.768	0.577	0.441	0.342
64				0.908	0.787	0.590	0.449	0.345
66				0.927	0.805	0.603	0.456	0.346
68				0.945	0.823	0.615	0.462	0.348
70				0.963	0.840	0.627	0.468	0.349
72				0.981	0.857	0.638	0.473	0.349
74				1.000	0.874	0.649	0.478	0.348
76					0.891	0.660	0.482	0.347
78					0.909	0.670	0.486	0.346
80					0.927	0.680	0.489	0.343